WADC TECHNICAL REPORT 55-290

THE DEVELOPMENT OF FIBROUS GLASSES HAVING HIGH ELASTIC MODULI

GEORGE R. MACHLAN

OWENS-CORNING FIBERGLAS CORPORATION
NEWARK, OHIO

NOVEMBER 1955

WRIGHT AIR DEVELOPMENT CENTER

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MATERIALS LABORATORY
CONTRACT No. AF 33(616)-2422
PROJECT No. 7340
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WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
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Carpenter Litho & Prtg. Co., Springfield, O.
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FOREWORD

This report was prepared by Dr. George R. Machlan of the Research Laboratories, Owens-Corning Fiberglas Corporation, Newark, Ohio under USAF Contract No. AF 33(616)-2422. This contract was initiated under Project No. 7340, "Rubber, Plastic and Composite Materials", Task No. 73400, "Structural Plastics", formerly RDO No. 614-12, "Structural Plastics", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt. A.E. Morse acting as project engineer.

This report covers the period of work from June 1954 to July 1955.

The services of Mr. F. W. Glaze, the National Bureau of Standards, Dr. F. V. Tooley, University of Illinois, Dr. F. W. Preston, Preston Laboratories, and Dr. N. J. Kreidl, Bausch & Lomb Optical Company, for consultation on this investigation are gratefully acknowledged.

ABSTRACT

A fifty percent increase in modulus of elasticity of fibrous glass was achieved by the continuous formation of fibers of a calcium aluminate glass in a small textile glass bushing.

The resistance of these glasses to chemical attack by water and water vapor is much less than that of commercially produced textile fibrous glass. The glasses are resistant to hydrofluoric acid but are completely soluble in hydrochloric acid.

The dielectric constants of these glasses were found to be higher than the dielectric constant of present textile glass and the loss tangents were found to be approximately the same as that of present textile glass.

Several compositions were investigated which contained tin oxide as the major constituent but no glasses were found.

An exploratory study of glass-plastic combinations from the calcium aluminate glass was initiated. Volan A was found to be the best coupling agent tested for this glass.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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I. INTRODUCTION

High modulus fibrous glass was required primarily for reinforced plastic materials. Modulus of present fibrous "E" glass is approximately 10.5×10^6 psi and yields a reinforced plastic having a modulus of approximately 3×10^6 psi. If the modulus of the glass could be increased to 20×10^6 psi, the resulting reinforced plastic might have a modulus of approximately 5×10^6 psi or one half that of aluminum metal.

The development of high modulus silicate glasses did not seem feasible since the moduli of these glasses fell in the range 8×10^6 psi to 15×10^6 psi. The moduli of phosphate and borate glasses were less well known but there was no reason to believe that either of these glassy systems had moduli significantly different than the silicate glasses.

It was thought that a clue to the development of high modulus glasses might be obtained from the study of the moduli of the crystalline oxides. Vitreous silica had a modulus of 10×10^6 psi which corresponded very well to the silicate glasses as well as to the crystalline forms of silica. Oxides which had high crystalline moduli and which were possible glass formers were alumina, zirconia, titania and tin oxide. The only known glasses in any of these oxide systems were calcium aluminates. If the modulus of these aluminate glasses corresponded to the modulus of crystalline alumina, extremely high modulus glasses would be obtained. The modulus of crystalline alumina was known to be approximately 55×10^6 psi and spinel, a magnesium aluminate, was known to be approximately 30×10^6 psi. The formation of glass in the aluminate system with calcium oxide was also fortunate, since calcium oxide was known to increase the modulus of silicate glasses more than any other oxide.

Morey (1) reports that the addition of calcium oxide into silicate glasses gave the greatest increase in Young's modulus when substituted on a weight percent basis for silicon dioxide. Aluminum oxide did not increase the modulus of silicate glasses as much as would have been anticipated from the modulus of the crystalline alumina. The lower modulus of the alumina in the silicate glass was probably because the alumina entered the silica network in four-fold coordination rather than six-fold coordination as in corundum. The moduli of elasticity of the early calcium aluminate glasses were substantially greater than in the corresponding silicate glasses but the alumina was obviously present in four-fold coordination as in the silicate glass. This conclusion was in agreement with Zachariasen's (2) original requirement for glass formation, i.e., that the glass former must have a low coordination number.

It was further thought that the other high modulus oxides, titania, zirconia and tin oxide could be considered as modifying constituents to the calcium aluminate glasses or as possible glass formers in their own systems. Other oxides, such as the alkali metal oxides, the alkaline earth oxides were to be used as modifiers to obtain the properties desired for fiber formation. The oxides of zinc, copper, iron and manganese were to be investigated as possible modifiers to lower liquidus temperatures and to improve the chemical durability.

An investigation to develop a high elastic modulus glass for fibers was initiated at Owens-Corning Fiberglas Corporation in July, 1953, before the initiation of this contract. The investigation began with the development of glasses in the calcium aluminate system. This system was chosen because it was believed that the high modulus of calcium oxide and aluminum oxide would transfer into the glassy system.

Dr. F. W. Glaze of the National Bureau of Standards, at the 1953 Fall Meeting of the Glass Section of the American Ceramic Society at Rochester, New York, presented their work on calcium aluminate glasses for infrared transmission. In this work, Young's modulus was found to be higher for these glasses than the corresponding silicate glass.

The addition of oxides other than calcium and aluminum were made to obtain the necessary high temperature physical properties required for fiber formation. The calcium aluminate glasses in general have high liquidus temperatures, are extremely fluid melts, and have rapid rates of devitrification during cooling. These characteristics made fiberization of nearly all these glasses difficult by the continuous filament process. Only by the addition of small quantities of other oxides to lower the liquidus temperature and increase the viscosity of the melt was fiberization possible.

The addition of oxides, other than those of calcium and aluminum, also affected the modulus of elasticity of the resulting glass.

The alkali oxides normally lower temperatures, decrease the viscosity and decrease Young's modulus. These oxides were used in the compositions to decrease the liquidus temperature of the melt. The alkaline earth oxides cannot be characterized in the same way as the alkali metal oxides. The changes in viscosity, liquidus temperature and Young's modulus in the substitution of these oxides in a glass was dependent on the initial composition and how the substitution was made.

Titanium dioxide and zirconium dioxide were used in the early composition work because it was believed these oxides would increase the modulus of the resulting glass. This belief was based on the high moduli of their respective crystalline oxides. Titanium dioxide tended to lower liquidus temperatures and to decrease the viscosity of the melt. Zirconium dioxide tended to raise the liquidus temperature and to increase the viscosity of the melt.

Silicon dioxide and boron oxide were added to the calcium aluminate compositions to lower the liquidus temperatures and increase the viscosity of the melt. These oxides lowered Young's modulus of the resulting glass.

Physical properties other than elastic modulus had to be considered as part of this investigation because of the demands of fiber formation and the applications of the glass fibers formed. The physical property requirements for a glass to be considered for the production of high modulus glass fibers were as follows:

1. The melt had to be viscous enough above the liquidus temperature that the fibers could be formed continuously from the melt.

2. The glass had to have a liquidus temperature low enough that it could be melted and worked in platinum bushings.

3. The chemical durability of the finished fiber had to be comparable to that of present commercial fibrous glass.

4. The finished glass fiber had to have a strength comparable to that of present commercial fibrous glass.

II. MATERIALS, TESTING PROCEDURES AND EQUIPMENT

The batch materials used in the compositions reported were as follows:

No. 6 limestone flour from National Gypsum of Bellefonte, Pa. was the source of calcium oxide.

C-31, hydrated alumina from Aluminum Company of America was the source of aluminum oxide.

Novacite from Malvern Minerals of Hot Springs, Arkansas was the source of silicon dioxide.

All other materials used were of technical grade or better.

The sodium oxide was added as technical grade sodium nitrate. The barium oxide, potassium oxide and lithium oxide were added as their respective carbonates.

All compositions are recorded as calculated to the batch and do not necessarily represent the exact composition of the finished glass. No chemical analyses were made of the glasses.

All melting of the compositions was done by one of the following methods:

1. Small exploratory bead melts were made on a platinum strip heated electrically.

2. Small ten to twenty gram batches were melted in platinum crucibles in a platinum wound electric furnace.

3. Large batches of one thousand grams or more were melted in a gas fired Remmey muffle furnace.

The first method mentioned above was the hot stage for the hot stage microscope. This melting procedure and apparatus is described in Appendix I, page 79.

Viscosity measurements on the glasses were made using the Brookfield viscometer as described in Appendix II, page 81.

Liquidus temperatures were determined on the hot stage microscope and by the gradient method as described in Appendix III, page 84.

The surface tension of a few glasses was determined by the maximum bubble pressure method as described in Appendix IV, page 87.

Young's moduli were determined for both bulk samples and fiber samples by the sonic method as described in Appendix V, page 90.

The fiber forming was done from a platinum bushing as described in Appendix VI, page 98.

Tensile strength of a few fibers were determined with the apparatus described in Appendix VII, page 101.

Glass-plastic combination rod samples were prepared for testing as described in Appendix VIII, page 104.

III. COMPOSITIONAL STUDIES

a. Phase I. Work Prior to Contract

The first phase of this investigation was to determine in an exploratory manner the extent of glass formation in the calcium aluminate system, the moduli of elasticity of these glasses and if properties compatible with fiber formation could be obtained.

The compositions studied in the first phase are listed with their respective melting temperatures and liquidus temperatures in Table I. (pg.9). The melting and liquidus temperatures shown in Table I are not precise, since they were obtained from examination of the melts on a hot stage microscope, Appendix I, (pg.79), and only comparative values could be obtained. The liquidus temperatures, in particular, are subject to large errors, since they were dependent upon the rate of crystallization of the melt and the rate at which the temperature of the stage was changed. All compositions in Table I up to No. 146 are expressed in mole percent. All those beyond No. 146 are expressed in cation percent after Sun. (4). Mole percent, means that each of the oxides was expressed in its usual stoichiometric manner; for example, Na_2O for sodium oxide, CaO for calcium oxide, Al_2O_3 for aluminum oxide. Cation percent means that each of the oxides was expressed with unit cation; for example, $NaO_{0.5}$ for sodium oxide, CaO for calcium oxide, $AlO_{1.5}$ for aluminum oxide.

In Table I, page 9 , the liquidus temperatures and melting temperatures were determined on the hot stage microscope. (Appendix I.). The letter "g" beside the melting temperature signifies that glass was formed when melt was quenched rapidly on the hot stage. The letter "d" signifies that the composition melted at the temperature shown but devitrified on quenching. The letter "pd" indicates melting but partial devitrification on cooling and the letter "s" indicates that the composition did not melt at the temperature shown. An asterisk (*) after the letter "g" indicates that devitrification did occur in melts larger than those used on the hot stage.

The best glass in a series was determined from the melting temperature and liquidus temperature as observed and the appearance of devitrification in the glass when produced in melts of ten grams or more.

Compositions Nos. 1 - 4 were the initial compositions melted in this series and were in the three component system 2 $CaO \cdot SiO_2$ - CaO - $Na_2O \cdot 6\ Al_2O_3$. All these compositions melted at 2900°F. on the hot stage microscope. Glass No. 2 was taken as a base glass because of the absence of silica.

Compositions Nos. 5 - 8 were the initial introductions of TiO_2 into the compositions. The TiO_2 was added as $Na_2O \cdot TiO_2$. Small additions of TiO_2 lower the liquidus temperatures but large additions increase the liquidus temperature, decrease the viscosity of the melt and increase the devitrification rate.

Compositions Nos. 9 - 24 and 34 - 47 were in the three component diagram CaO - $Na_2O \cdot 6\ Al_2O_3$ - $Na_2O \cdot TiO_2$. The lowest liquidus temperatures were found in the glasses containing 5% $Na_2O \cdot TiO_2$ and 40 - 50% $Na_2O \cdot 6\ Al_2O_3$. These glasses are Nos. 9, 38 and 39.

Compositions Nos. 25 - 37 and Nos. 48 - 59 were in the three component field CaO - $Na_2O \cdot 6\ Al_2O_3$ - TiO_2. The lowest liquidus glasses containing TiO_2 were on the 5% TiO_2 level and 40 - 50% $Na_2O \cdot 6\ Al_2O_3$.

Compositions Nos. 60 - 80 were systematic substitutions of MgO and BaO for CaO.

Compositions Nos. 81 - 103 were a systematic substitution of the LiO_2 and K_2O for Na_2O in Glass No. 67. The optimum ratio of $Na_2O:Li_2O:K_2O$ was found to be 5:4:1 found in No. 90.

Compositions Nos. 104 - 113 were a systematic substitution of ZrO_2 for CaO in No. 67. The addition of ZrO_2 up to 25% of the total CaO could be accomplished. At 25% the melting temperature was approaching the limit of the maximum available temperature of the hot stage microscope. A definite phase separation was noted in these glasses when melted in large amounts in platinum crucibles.

Compositions Nos. 114 - 123 were a systematic substitution of ZnO for CaO. This substitution did lower the apparent melting temperature and liquidus temperature. Large melts, however, could not be produced without excessive devitrification.

Compositions Nos. 127 - 134 were a continuation of the substitution of ZrO_2 for CaO from 25% to 50% of the total CaO. The melting temperature went above the temperature available on the hot stage after about 30% of the total CaO had been substituted.

Compositions Nos. 135 - 138 were substitutions of CuO and Cu_2O for Na_2O in No. 134. All of these compositions devitrified while cooling on the hot stage.

Compositions Nos. 139 - 145 were random substitutions of ZnO, Fe_2O_3 and SiO_2 into these compositions. Composition No. 134 did not melt to a clear glass at 2950 °F. Compositions Nos. 140 - 144 melted to clear glasses on the hot stage of the microscope, but devitrified when melted in large quantities. Composition No. 145 did not melt at 2900°F.

Composition No. 146 marks the initiation of cation substitution rather than molar substitution.

From Compositions Nos. 146 to 367, random substitutions of all components and additions of $FeO_{1.5}$, SiO_2, MnO_2, MnO were studied. The best compositions found in this random study were Nos. 166, 197, 211, 310, 313, 314, 336 and 339.

Compositions Nos. 368 - 394 were a systematic substitution of MgO and BaO for CaO in Glass No. 313. The best glass found in this substitution was No. 386.

Compositions Nos. 395 - 426 were a systematic study of the substitution of TiO_2 and ZrO_2 for $AlO_{1.5}$ in Ca 386. Glasses in which more than 5% of the total acidic components ($AlO_{1.5}$ + TiO_2 + ZrO_2) was either TiO_2 or ZrO_2 did not melt into glasses at 2750°F. or devitrified on cooling.

Compositions Nos. 427 - 444 were a systematic variation of the total alkali, alkaline earth and acid components based on the ratio of each group as found in No. 402. In this study all compositions containing more than 17.5% total alkali and more than 57.5% total acidic components did not melt to clear glasses. The best glass found in this study was No. 432.

Compositions Nos. 445 - 463 were a systematic study of the substitution of K_2O and Li_2O for Na_2O in Glass No. 432. Glasses were formed throughout the entire substitution. Compositions Nos. 461, 462 and 463 could not be melted to clear glasses in small crucibles containing ten gram melts. Glass No. 451 was the best glass in this group.

Compositions Nos. 464 - 483 were a systematic substitution of $BO_{1.5}$ and SiO_2 for $AlO_{1.5}$. Compositions Nos. 481 - 483 were never melted because several good glasses were found without going beyond 6% of the total acidic oxide content with $BO_{1.5}$. The properties of these glasses became better as the substitution of SiO_2 for Al_2O_3 increased.

Compositions Nos. 484 - 501 were a systematic substitution of MgO and BaO for CaO in Glass No. 451. The best glass found in this group was No. 492.

Compositions Nos. 502 - 514 were a continuation of the substitution of SiO_2 and $BO_{1.5}$ for $AlO_{1.5}$ started in Nos. 464 - 483. The glass properties continued to improve as SiO_2 was substituted for $AlO_{1.5}$. Glasses 505 B, 506 B, 507 B, 508 B, 509 B were produced later in the investigation to determine the effect of the BeO substitution for CaO in these compositions.

Compositions Nos. 515 - 531 and Nos. 552 - 561 were a study of the systematic substitution of ZnO and PbO for CaO in glass No. 508. All compositions devitrified on cooling. The letters "dm" after the melting temperature in this group indicates the presence of reduced metal in these melts. All melts in this group were made in refractory crucibles rather than platinum.

Compositions Nos. 532 - 551 were a study of the systematic substitution of ZrO_2 and TiO_2 for $AlO_{1.5}$ and one half the CaO was added as CaF_2 to lower the melting and liquidus temperature.

Compositions Nos. 552 - 591 were high ZnO containing compositions. None of these compositions fused at 2900°F.

Compositions Nos. 592 - 631 were a variation of the alkali, alkaline earth and acidic groups in the proportions found in Composition No. 581. None of these compositions melted at 2900°F.

Table II, page 41, contains the results of Young's moduli measurements, viscosity and density measurements for the best glasses found in this early part of the investigation. The moduli and density values reported in Table II are all for annealed glass. The highest modulus glass found in this early investigation is No. 197 which had a modulus at 16.7×10^6 psi and the lowest modulus glass found in this group was No. 508 which had a modulus of 15.42×10^6 psi. The density of all the glasses in this series fell in the range of 2.8 to 3.2 gms/ml. Table II indicates the viscosity of the melt by recording the temperature at which the logarithm of the viscosity, in poises, was 0.5, 1.0, 1.5 and 2.

Viscosity measurements were generally limited to temperatures below 2750°F. and to temperatures above the liquidus temperature of the glass or the point at which the melt devitrified in the measuring apparatus. The most viscous glass shown in Table II, therefore, is No. 395, and the most fluid glass shown in Table II is No. 166. All viscosity measurements reported in Table II were made using the Brookfield Viscometer as described in Appendix I.

The formation of fibers in the standard one hole bushing was attempted on all glasses listed in Table II. Small quantities of fiber could be formed on Nos. 492, 506, 508 and 511. The best of these was No. 508. Attempts to fiberize all of the other glasses resulted in either the glass being too fluid to form fibers or in devitrification of the glass in the bushing tips. A more detailed discussion of the formation of fibers of these glasses will be given in a later section of this report.

b. Phase II. Work Since June 1954

The next phase of the investigation was a systematic study of variations of the constituents to obtain the highest possible modulus with the best viscosity liquidus temperature relationship for fiber formation. The compositions studied in this phase are shown in Table III, page 44.

TABLE I.

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	Na_2O	Al_2O_3	TiO_2	SiO_2	Melting Temp. °F.	Liquidus Temp. °F.
1	41.48	7.48	44.73		6.31	2900 g	2700
2	53.37	6.64	40.00			2950 g	2600
3	50.42	6.48	38.76		4.34	2750 g	2600
4	43.09	7.47	44.68		4.75	2800 g	2600
5	35.46	12.80	46.72	5.02		2900 d	2600
6	39.36	12.30	43.32	5.02		2900 d	2550
7	29.40	13.69	51.84	5.05		2900 d	2800
8	31.13	17.61	41.22	10.03		2850 pd	2700
9	50.00	10.7	34.3	5.3		2680 pd	2175
10	40.00	15.7	34.30	10.00		2850 g	2700
11	28.00	21.00	36.00	15.00		3000 g	2540
12	20.00	22.10	42.90	15.00		2900 d	2450
13	20.00	18.60	51.40	10.00		2800 d	2550
14	20.00	15.00	60.00	5.00		2900 d	2700
15	24.00	25.10	30.90	20.00		2950 d	2550
16	30.00	24.30	25.70	20.00		2950 d	2850
17	40.00	22.90	17.10	20.00		2950 s	--
18	40.00	19.30	25.70	15.00		2950 s	--
19	40.00	26.40	8.60	25.00		2450 d	--
20	30.00	27.90	17.10	25.00		2950 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	Na_2O	Al_2O_3	TiO_2	Melting Temp. °F.	Liquidus Temp. °F.
21	20.00	29.30	25.70	25.00	2930 d	2620
22	10.00	30.70	34.30	25.00	2900 d	2650
23	10.00	27.10	42.90	20.00	2900 s	--
24	10.00	23.60	51.40	15.00	2770 g	2500
25	51.50	6.20	38.50	10.00	2800 g	2600
26	55.00	5.80	35.00	10.00	2770 g	2500
27	45.00	7.50	45.00	10.00	2800 g	2600
28	48.50	6.10	36.50	15.00	3000 s	--
29	55.00	5.00	30.00	15.00	2800 d	2600
30	45.00	6.70	40.00	15.00	2950 s	--
31	46.00	5.70	34.00	15.00	2950 s	--
32	50.00	5.00	30.00	20.00	2950 s	--
33	40.00	6.70	40.00	20.00	2950 s	--
34	46.20	7.70	46.20	--	2900 d	2200
35	41.20	8.40	50.40	--	2950 pd	2550
36	36.40	9.10	54.50	--	2950 s	--
37	31.60	9.70	58.70	--	2950 s	--
38	44.40	11.10	40.00	4.40	2870 g	2300
39	39.70	11.70	44.10	4.40	2920 g	2350
40	35.00	12.40	48.20	4.40	2900 d	2500

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	Na_2O	Al_2O_3	TiO_2	MgO	Melting Temp. °F.	Liquidus Temp. °F.
41	30.40	13.00	52.20	4.30		2950 s	--
42	25.90	13.60	56.10	4.30		2950 s	--
43	25.00	16.70	50.00	8.30		2970 d	2670
44	29.40	16.10	46.10	8.40		2920 d	2700
45	33.80	15.50	42.30	8.50		2900 pd	2670
46	27.90	17.90	43.50	10.70		2950 pd	2670
47	23.40	22.10	39.00	15.60		2850 pd	2500
48	46.50	7.00	41.80	4.70		2850 g	2375
49	41.60	7.70	46.20	4.60		2800 g	2400
50	36.60	8.40	50.40	4.60		-- s	--
51	31.80	9.10	54.50	4.50		-- s	--
52	36.90	7.70	46.20	9.20		2850 d	2650
53	32.10	8.40	50.40	9.20		2950 d	2780
54	27.30	9.10	54.50	9.10		2950 s	--
55	27.50	8.40	50.40	13.70		2920 d	2550
56	32.30	7.70	46.20	13.80		2920 d	2650
57	37.20	7.00	41.80	14.00		2950 s	--
58	32.60	7.00	41.80	18.60		2940 d	2800
59	27.70	7.00	46.20	18.50		2950 s	--
60	40.21	6.41	38.49	3.76	5.13	2770 g	2250

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	Na_2O	Al_2O_3	TiO_2	Melting Temp. °F.	Liquidus Temp. °F.
61	41.07	10.27		6.41	38.49	3.76	2720 g	2150
62	35.94	15.40		6.41	38.49	3.76	2900 s	--
63	30.80	20.54		6.41	38.49	3.76	2950 s	--
64	25.67	25.67		6.41	38.49	3.76	2950 s	--
65	20.54	30.80		6.41	38.49	3.76	2950 s	--
66	46.21	--	5.13	6.41	38.49	3.75	2710 d	2420
67	41.07	5.13	5.13	6.41	38.49	3.76	2720 g	2175
68	35.94	10.27	5.13	6.41	38.49	3.76	2750 pd	2275
69	30.80	15.40	5.13	6.41	30.49	3.71	2950 pd	2300
70	25.67	20.54	5.13	6.41	38.49	3.76	2950 s	--
71	20.54	25.67	5.13	6.41	38.49	3.76	2950 s	--
72	41.07	--	10.27	6.41	38.49	3.76	2930 d	2400
73	43.64	5.13	2.57	6.41	38.49	3.76	2620 g	2080
74	41.07	7.70	2.57	6.41	38.49	3.76	2700 g	2250
75	38.80	10.27	2.57	6.41	38.49	3.76	2720 g	2220
76	35.94	12.84	2.57	6.41	38.49	3.76	2910 pd	2500
77	38.50	5.13	7.70	6.41	38.49	3.76	2720 pd	2120
78	35.94	7.70	7.70	6.41	38.49	3.76	2750 d	2300
79	33.37	10.27	7.70	6.41	38.49	3.76	2700 pd	2400
80	30.80	12.84	7.70	6.41	38.49	3.76	2950 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	Na_2O	K_2O	Li_2O	Al_2O_3	TiO_2	Melting Temp. °F.	Liquidus Temp. °F.
81	41.07	5.13	5.13	5.77	--	0.64	38.49	3.76	2700 g	2100
82	41.07	5.13	5.13	5.13	--	1.28	38.49	3.76	2670 g	2100
83	41.07	5.13	5.13	4.49	--	1.92	38.49	3.76	2650 d	2350
84	41.07	5.13	5.13	3.85	--	2.56	38.49	3.76	2600 g	2100
85	41.07	5.13	5.13	3.21	--	3.20	38.49	3.76	2650 g	2100
86	41.07	5.13	5.13	5.77	0.64	--	38.49	3.76	2700 g	2260
87	41.07	5.13	5.13	5.13	0.64	0.64	38.49	3.76	2620 pd	2300
88	41.07	5.13	5.13	4.49	0.64	1.28	38.49	3.76	2640 g	2300
89	41.07	5.13	5.13	3.85	0.64	1.92	38.49	3.76	2600 g	2200
90	41.07	5.13	5.13	3.21	0.64	2.56	38.49	3.76	2600 g	2150
91	41.07	5.13	5.13	2.56	0.64	3.21	38.49	3.76	2600 g	2100
92	41.07	5.13	5.13	5.13	1.28	--	38.49	3.76	2600 g	2100
93	41.07	5.13	5.13	4.49	1.28	0.64	38.49	3.76	2620 g	2100
94	41.07	5.13	5.13	3.85	1.28	1.28	38.49	3.76	2600 g	2050
95	41.07	5.13	5.13	3.21	1.28	1.92	38.49	3.76	2570 g	2200
96	41.07	5.13	5.13	2.56	1.28	2.56	38.49	3.76	2600 d	2400
97	41.07	5.13	5.13	1.92	1.28	3.21	38.49	3.76	2700 d	2520
98	41.07	5.13	5.13	4.49	1.92	--	38.49	3.76	2750 g	2100
99	41.07	5.13	5.13	3.85	1.92	0.64	38.49	3.76	2750 pd	2200
100	41.07	5.13	5.13	3.21	1.92	1.28	38.49	3.76	2650 d	2500

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	Na_2O	K_2O	Li_2O	Al_2O_3	TiO_2	ZrO_2	ZnO	Melting Temp. °F.	Liquidus Temp. °F.
101	41.07	5.13	5.13	3.85	2.56	--	38.49	3.76			2800 pd	2520
102	41.07	5.13	5.13	3.21	2.56	0.64	38.49	3.76			2660 pd	2400
103	41.07	5.13	5.13	3.21	3.21		38.49	3.76			2700 g	2100
104	40.04	5.13	5.13	6.41			38.49	3.76	1.03		2700 g	2400
105	39.02	5.13	5.13	6.41			38.49	3.76	2.05		2700 g*	2200
106	37.99	5.13	5.13	6.41			38.49	3.76	3.08		2700 pd	2500
107	36.96	5.13	5.13	6.41			38.49	3.76	4.11		2720 g*	2440
108	35.94	5.13	5.13	6.41			38.49	3.76	5.13		2720 g	2420
109	34.91	5.13	5.13	6.41			38.49	3.76	6.16		not melted	
110	33.88	5.13	5.13	6.41			38.49	3.76	7.19		2750 g	2200
111	32.86	5.13	5.13	6.41			38.49	3.76	8.21		2800 g*	2200
112	31.83	5.13	5.13	6.41			38.49	3.76	9.24		2800 g	2200
113	30.80	5.13	5.13	6.41			38.49	3.76	10.27		2850 g*	2150
114	40.04	5.13	5.13	6.41			38.49	3.76		1.03	2800 pd	2400
115	39.02	5.13	5.13	6.41			38.49	3.76		2.05	2800 g	2300
116	37.99	5.13	5.13	6.41			38.49	3.76		3.08	2700 g	2200
117	36.96	5.13	5.13	6.41			38.49	3.76		4.11	2700 g	2300
118	35.94	5.13	5.13	6.41			38.49	3.76		5.13	2700 g	2220
119	34.91	5.13	5.13	6.41			38.49	3.76		6.16	2740 g	2200
120	33.88	5.13	5.13	6.41			38.49	3.76		7.19	2850 pd	2500

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	Na_2O	Al_2O_3	TiO_2	ZrO_2	SiO_2	ZnO	K_2O	Melting Temp. °F.	Liquidus Temp. °F.
121	32.86	5.13	5.13	6.41	38.49	3.76			8.21		2700 g	2300
122	31.83	5.13	5.13	6.41	38.49	3.76			9.24		2750 g	2200
123	30.80	5.13	5.13	6.41	38.49	3.76			10.27		2680 g	2150
124	29.78	5.13	5.13	6.41	38.49	3.76	11.29				2850 g	2350
125	28.75	5.13	5.13	6.41	38.49	3.76	12.32				2880 g	2350
126	27.72	5.13	5.13	6.41	38.49	3.76	13.35				2930 pd	2400
127	26.70	5.13	5.13	6.41	38.49	3.76	14.37				2980 s	--
128	25.67	5.13	5.13	6.41	38.49	3.76	15.40				did not melt	
129	24.64	5.13	5.13	6.41	38.49	3.76	16.43				did not melt	
130	23.62	5.13	5.13	6.41	38.49	3.76	17.45				did not melt	
131	22.59	5.13	5.13	6.41	38.49	3.76	18.48				did not melt	
132	21.56	5.13	5.13	6.41	38.49	3.76	19.51				did not melt	
133	20.53	5.13	5.13	6.41	38.49	3.76	20.54				did not melt	
134	34.56	5.32	3.16	6.41	38.49	3.76	10.27				2900 g	2075
135	34.56	4.32	2.16	5.13	38.49	3.76	10.27	Cu_2O 1.28	CuO 2.56		2800 pd	2200
136	34.56	4.32	2.16	4.49	38.49	3.76	10.27	1.92	3.84		2850 pd	2400
137	34.56	4.32	2.16	3.85	38.49	3.76	10.27	2.56	5.12		did not melt	
138	34.56	4.32	2.16	3.21	38.49	3.76	10.27	3.20	6.40		did not melt	
139	24.29	4.32	2.16	5.13	38.49	3.76	10.27	ZnO 10.27		1.28	2950 pd	2400
140	33.99	4.25	2.13	6.31	37.86	3.7;	10.10		SiO_2 1.38	Fe_2O_3 0.26	2750 g	2150

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	Na_2O	Al_2O_3	TiO_2	ZrO_2	SiO_2	Fe_2O_3	Melting Temp. °F.	Liquidus Temp. °F.
141	33.52	4.19	2.10	6.22	37.34	3.65	9.96	2.76	0.26	2750 g	2250
142	33.05	4.14	2.07	6.13	36.81	3.60	9.82	4.12	0.26	2850 g	2250
143	32.57	4.08	2.04	6.05	36.29	3.55	9.68	5.48	0.26	2750 g	2250
144	32.11	4.02	2.01	5.96	35.77	3.50	9.55	6.82	0.26	2780 g	2100
145	31.16	3.90	1.95	5.76	34.71	3.40	9.26	9.79	0.05	2800 s	--
146	23.66	2.98	1.49	$NaO_{0.5}$ 8.85	$AlO_{1.5}$ 46.05	2.60	7.09	7.09		2750 g	2500
147	27.21	2.98	1.49	8.85	49.59	2.60	3.54	3.55		2600 g	2500
148	23.66	2.98	1.49	8.85	53.14	2.60	3.54	3.55		2650 g	2500
149	23.66	4.47		8.85	53.14		4.84	4.85		2800 g	2500
150	24.41	3.72		8.85	53.14		4.84	4.85		2800 g	2500
151	25.15	2.98		8.85	53.14		4.84	4.85		2800 g	2500
152	25.15	2.98		8.85	55.94		3.54	3.55		2850 g	2550
153	25.15	2.98		8.85	54.44		4.19	4.20		2800 g	2525
154	25.15	2.98		8.85	56.54		6.29			2850 d	2650
155	25.15	2.98		8.85	58.64		4.19			2850 d	2650
156	25.15	2.98		8.85	54.44		8.39			2950 s	--
157	24.41	3.72		8.85	54.44		8.39			2950 s	--
158	23.66	4.47		8.85	54.44		8.39			2970 s	--
159	24.41	3.72		8.85	51.84	2.60	8.39			2970 d	2300
160	24.41	3.72		8.85	53.14	1.30	8.39			did not melt	

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$Al0_{1.5}$	$Ti0_2$	$Zr0_2$	$Fe0_{1.5}$	$K0_{0.5}$	Mn0	Melting Temp. °F.	Liquidus Temp. °F.
161	24.50	4.08	4.08	9.28	55.64	2.42					2680 g	2000
162	21.98	3.66	3.66	9.76	58.60	2.34					2680 d	2100
163	27.42	7.09	4.57	7.98	41.90	2.52	2.52				2680 g	2400
164	24.70	6.56	4.12	8.54	51.22	2.44	2.44				2680 g	2150
165	22.15	6.05	3.69	9.06	54.33	2.36	2.36				2680 g	2200
166	19.75	5.58	3.29	9.54	57.25	2.29	2.29				2680 d	2200
167	27.65	9.69	4.61	7.21	43.22	2.54	5.08				3000 s	--
190	21.05	3.51	3.51	4.68	52.63	7.02	5.26	-	2.34	-	2800 g	2300
191	21.05	3.51	3.51	4.68	52.63	3.51	5.26	-	2.34	3.51	2950 g	2400
192	21.05	3.51	3.51	4.68	52.63	3.51	5.26	3.51	2.34	-	2800 g	2100
193	21.05	3.51	3.51	4.68	52.63	2.34	5.26	2.34	2.34	2.34	2800 g	2200
194	21.05	3.51	3.51	4.68	52.63	-	5.26	-	2.34	7.02	2800 g	2300
195	21.05	3.51	3.51	4.68	52.63	-	5.26	3.51	2.34	3.51	2800 g	2200
196	21.05	3.51	3.51	4.68	52.63	-	5.26	7.02	2.34	-	2800 g	2150
197	20.45	3.41	3.41	4.55	56.82	3.41	5.68	-	2.27	-	2850 g	2100
198	20.45	3.41	3.41	4.55	56.82	1.70	5.68	-	2.27	1.70	2950 s	--
199	20.45	3.41	3.41	4.55	56.82	1.70	5.68	1.70	2.27	-	2950 g	2100
200	20.45	3.41	3.41	4.55	56.82	1.14	5.68	1.14	2.27	$Mn0_2$ 1.14	2860 g	2300

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$AlO_{1.5}$	$KO_{0.5}$	ZrO_2	TiO_2	MnO_2	$FeO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
201	20.45	3.41	3.41	4.55	56.82	2.27	5.68	-	3.41	-	2830 g	2300
202	20.45	3.41	3.41	4.55	56.82	2.27	5.68	-	1.70	1.70	2900 g	2350.
203	20.45	3.41	3.41	4.55	56.82	2.27	5.68	-	-	3.41	2970 d	2550
204	17.40	2.90	2.90	4.42	60.78	2.21	6.08	3.31	-	--	2950 s	--
205	17.40	2.90	2.90	4.42	60.78	2.21	6.08	1.66	1.66	--	2950 s	--
206	17.40	2.90	2.90	4.42	60.78	2.21	6.08	1.66	-	1.66	2950 s	--
207	17.40	2.90	2.90	4.42	60.78	2.21	6.08	1.11	1.11	1.11	2950 s	--
208	17.40	2.90	2.90	4.42	60.78	2.21	6.08	-	3.31	--	2950 s	--
209	17.40	2.90	2.90	4.42	60.78	2.21	6.08	-	1.66	1.66	2950 s	--
210	17.40	2.90	2.90	4.42	60.78	2.21	6.08	-	-	3.31	2950 s	--
211	17.31	2.89	2.89	8.79	54.94	4.40	5.49	3.3-	-	--	2750 g	2100
212	17.31	2.89	2.89	8.79	54.94	4.40	5.49	1.65	1.65	--	2870 g	2650
213	17.31	2.89	2.89	8.79	54.94	4.40	5.49	1.65	-	1.65	2750 g	2300
214	17.31	2.89	2.89	8.79	54.94	4.40	5.49	1.10	1.10	1.10	2800 g	2300
215	17.31	2.89	2.89	8.79	54.94	4.40	5.49	-	3.30	--	2750 g	2300
216	17.31	2.89	2.89	8.79	54.94	4.40	5.49	-	1.65	1.65	2850 g	2350
217	17.31	2.89	2.89	8.79	54.94	4.40	5.49	-	-	3.30	2750 g	2350
218	14.44	2.41	2.41	8.55	58.83	4.28	5.88	3.21	-	--	2950 d	2500
219	14.44	2.41	2.41	8.55	58.83	4.28	5.88	1.6	1.60	--	2950 s	--
220	14.44	2.41	2.41	8.55	58.83	4.28	5.88	1.60	-	1.60	2950 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$AlO_{1.5}$	$KO_{0.5}$	ZrO_2	TiO_2	MnO_2	$FeO_{1.5}$	Melting Temp. °.F	Liquidus Temp. °F.
221	19.44	2.41	2.41	8.55	58.83	4.28	5.88	1.07	1.07	1.07	2950 S	--
222	14.44	2.41	2.41	8.55	58.83	4.28	5.88	-	3.21	-	2970 d	2300
223	14.44	2.41	2.41	8.55	58.83	4.28	5.88	-	1.60	1.60	2950 s	--
224	14.44	2.41	2.41	8.55	58.83	4.28	5.88	-	-	3.21	2950 s	--
225	12.03	2.01	2.00	8.55	58.83	4.28	5.88	6.42	-	-	2950 s	--
226	12.03	2.01	2.00	8.55	58.83	4.28	5.88	3.21	3.21	-	2950 s	---
227	12.03	2.01	2.00	8.55	58.83	4.28	5.88	3.21	-	3.21	2950 s	--
228	12.03	2.01	2.00	8.55	58.83	4.28	5.88	2.14	2.14	2.14	2950 s	--
229	12.03	2.01	2.00	8.55	58.83	4.28	5.88	-	6.42	-	2950 s	--
230	12.03	2.01	2.00	8.55	58.83	4.28	5.88	-	3.21	3.21	2950 s	--
231	12.03	2.00	1.99	8.55	58.83	4.28	5.88	-	-	6.42	2950 s	--
232	11.97	2.00	1.99	12.77	53.18	6.38	5.32	6.38	-	-	2950 s	--
233	11.97	2.00	1.99	12.77	53.18	6.38	5.32	3.19	3.19	-	2950 s	--
234	11.97	2.00	1.99	12.77	53.18	6.38	5.32	3.10	-	3.19	2950 s	--
235	11.97	2.00	1.99	12.77	53.18	6.38	5.32	2.13	2.13	2.13	2950 s	--
236	11.97	2.00	1.99	12.77	53.18	6.38	5.32	-	6.38	-	2950 s	--
237	11.97	2.00	1.99	12.77	53.18	6.38	5.32	-	3.19	3.19	2950 s	--
238	11.97	2.00	1.99	12.77	53.18	6.38	5.32	-	-	6.38	2950 s	--
239	11.66	1.95	1.94	12.43	57.00	6.22	5.70	3.11	-	-	2950 s	--
240	11.66	1.95	1.94	12.43	57.00	6.22	5.70	1.55	1.55	-	2950 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$AlO_{1.5}$	$KO_{0.5}$	ZrO_2	TiO_2	MnO_2	$FeO_{1.5}$	SiO_2	Melting Temp. °F.	Liquidus Temp. °F.
241	11.66	1.95	1.94	12.43	57.00	6.22	5.70	1.55	-	1.55	-	2950 s	--
242	11.66	1.95	1.94	12.43	57.00	6.22	5.70	1.04	1.04	1.04	-	2950 s	--
243	11.66	1.95	1.94	12.43	57.00	6.22	5.70	-	3.11	-	-	2950 s	--
244	11.66	1.95	1.94	12.43	57.00	6.22	5.70	-	1.55	1.55	-	2950 s	--
245	11.66	1.95	1.94	12.43	57.00	6.22	5.70	-	-	3.11	-	2950 s	--
246	9.32	1.55	1.55	12.43	57.00	6.22	5.70	6.22	-	-	-	2950 s	--
247	9.32	1.55	1.55	12.43	57.00	6.22	5.70	3.11	3.11	-	-	2950 s	--
248	9.32	1.55	1.55	12.43	57.00	6.22	5.70	3.11	-	3.11	-	2950 s	--
249	9.32	1.55	1.55	12.43	57.00	6.22	5.70	2.07	2.07	2.07	-	2950 s	--
250	9.32	1.55	1.55	12.43	57.00	6.22	5.70	-	6.22	-	-	2950 s	--
251	9.32	1.55	1.55	12.43	57.00	6.22	5.70	-	3.11	3.11	-	2950 s	--
252	9.32	1.55	1.52	12.43	57.00	6.22	5.70	-	-	6.22	-	2950 s	--
253	19.45	3.41	3.41	4.55	56.82	2.27	5.68	3.41	-	-	1.00	2870 g	2350
254	18.45	3.41	3.41	4.55	56.82	2.27	5.68	3.41	-	-	2.00	2800 g	2100
255	17.45	3.41	3.41	4.55	56.82	2.27	5.68	3.41	-	-	3.00	2850 d	2700
256	16.45	3.41	3.41	4.55	56.82	2.27	5.68	3.41	-	-	4.00	2900 d	2400
257	15.45	3.41	3.41	4.55	56.82	2.27	5.68	3.41	-	-	5.00	2850 d	2400
258	14.45	3.41	3.41	4.55	56.82	2.27	5.68	3.41	-	-	6.00	2950 s	--
259	13.45	3.41	3.41	4.55	56.82	2.27	5.68	3.41	-	-	7.00	2950 s	--
260	19.75	3.29	3.29	6.36	57.25	3.18	5.58	2.29	-	-	-	2750 g	2250

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	ZrO_2	TiO_2	Melting Temp. °F.	Liquidus Temp. °F.
261	20.45	3.41	3.41	4.55	2.27	56.82	6.80	2.29	2750 g	2350
262	20.45	3.41	3.41	4.55	2.27	57.94	5.68	2.29	2750 g	2220
263	20.00	3.50	3.50	4.50	2.00	59.00	5.50	2.00	2750 g	2300
264	20.00	3.50	3.50	4.50	2.00	58.00	6.50	2.00	2800 g	2300
265	20.00	3.50	3.50	4.00	2.50	58.00	6.50	2.00	2750 g	2250
266	19.00	3.50	3.50	4.00	2.50	58.00	6.50	3.00	2750 g	2300
267	19.00	3.50	3.50	4.00	2.50	59.00	6.50	2.00	2750 g	2350
268	19.00	3.50	3.50	4.00	2.50	58.00	7.50	2.00	2850 g	2300
269	18.00	3.50	3.50	4.00	2.50	59.00	7.50	2.00	2920 pd	2550
270	18.00	4.50	2.50	4.00	2.50	59.00	7.50	2.00	2880 g	2550
271	17.50	4.50	2.50	4.00	2.50	59.00	7.50	2.50	2900 g	2500
272	17.00	4.50	2.50	4.00	2.50	59.00	7.50	3.00	2920 g	2650
273	17.00	4.50	3.00	4.00	2.50	59.[illegible]0	7.50	2.50	2970 d	2600
274	16.50	4.50	3.50	4.00	2.50	59.00	7.50	2.50	2850 d	2500
275	16.00	4.50	3.00	4.00	2.50	59.00	7.50	3.50	2960 d	2650
276	16.00	4.50	2.50	4.00	2.50	59.50	7.50	3.50	2970 s	--
277	19.00	4.50	2.50	4.00	2.50	59.59	4.50	3.50	2980 d	2450
278	18.50	4.50	2.50	4.00	2.50	60.00	4.50	3.50	2900 d	2500
279	19.50	4.50	1.50	4.00	2.50	60.00	4.50	3.50	2980 d	2500
280	18.50	4.50	2.50	4.00	2.50	59.00	7.50	1.50	2950 g	2500

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	ZrO_2	TiO_2	Melting Temp. °F.	Liquidus Temp. °F.
281	18.00	4.50	2.50	4.00	2.50	60.00	7.50	1.00	2900 g	2500
282	18.50	4.50	2.50	4.00	2.50	59.00	7.00	2.00	2900 g	2500
283	18.00	4.50	2.50	4.00	2.50	59.00	7.50	2.00	2900 g	2540
284	17.00	4.50	2.00	4.00	2.50	59.50	8.00	2.50	2970 s	--
285	18.50	4.50	2.00	4.00	2.50	59.50	8.00	1.00	2850 g	2450
286	17.00	4.50	2.00	4.00	2.50	61.00	8.00	1.00	2900 g	2350
287	17.50	4.00	2.00	4.00	3.00	60.50	8.00	1.00	2880 g	2300
288	18.00	4.00	2.00	4.00	3.00	60.00	8.00	1.00	2850 g	2400
289	18.50	4.00	2.00	4.00	2.50	60,00	8.00	1.00	2900 g	2300
290	17.50	4.50	2.50	4.50	3.00	59.00	7.50	1.50	2800 g	2300
291	17.00	4.00	2.50	5.00	3.50	59.00	7.50	1.50	2900 d	2600
292	16.50	4.00	2.00	5.50	4.00	59.00	7.50	1.50	2800 d	2600
293	16.00	4.00	2.00	6.50	4.00	59.00	7.50	1.00	2950 g	2450
294	15.50	3.50	2.00	7.00	4.50	59.00	7.50	1.00	2825 g	2400
295	15.00	3.50	1.50	8.00	4.50	59.00	7.50	1.00	2850 d	2300
296	14.00	3.50	1.50	8.50	5.00	59.00	7.50	1.00	2950 d	2700
297	13.00	3.50	1.50	9.00	5.50	59.00	7.50	1.00	2960 s	--
298	13.00	3.50	1.50	10.00	5.50	59.00	6.50	1.00	2980 d	2750
299	13.00	3.50	1.50	10.00	6.50	59.00	5.50	1.00	2920 d	2700
300	14.10	3.30	1.40	7.50	4.20	60.50	8.00	1.00	2950 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	ZrO_2	TiO_2	SiO_2	Melting Temp. °F.	Liquidus Temp. °F.
301	15.10	3.30	1.40	7.50	4.20	60.50	7.00	1.00	-	2950 s	--
302	16.10	3.30	1.40	7.50	4.20	60.50	5.00	1.00	-	2950 s	--
304	15.10	3.30	1.40	6.50	4.20	60.50	8.00	1.00	-	2950 s	--
305	16.10	3.30	1.40	6.50	4.20	60.50	7.00	1.00	-	2950 s	--
306	14.10	3.30	1.40	7.50	4.20	59.50	8.00	1.00	1.00	2950 s	--
307	14.10	3.30	1.40	7.50	4.20	58.50	8.00	1.00	2.00	2950 s	--
308	14.10	3.30	1.40	7.50	4.20	60.50	7.00	1.00	1.00	2950 s	--
309	14.10	3.30	1.40	7.50	4.20	60.50	6.00	1.00	2.00	2950 s	--
310	30.12	3.54	1.77	6.85	2.00	53.13	-	2.59	-	2720 g	1900
311	30.12	3.54	1.77	5.85	3.00	53.13	-	2.59	-	2700 g	2100
312	29.12	3.54	1.77	5.85	3.00	53.13	1.00	2.59	-	2620 g	2130
313	29.12	3.54	1.77	5.85	3.00	53.13	2.00	1.59	-	2650 g	1900
314	29.12	3.54	1.77	5.85	3.00	52.13	3.00	1.59	-	2780 g	1900
315	28.12	3.54	1.77	5.85	3.00	52.13	4.00	1.59	-	2800 g*	1950
316	28.12	3.54	1.77	5.85	3.00	52.13	5.00	0.59	-	2850 g*	2250
317	27.12	3.54	1.77	5.85	3.00	52.13	5.00	1.59	-	2900 g*	2300
318	26.12	3.54	1.77	5.85	3.00	53.13	5.00	1.59	-	2720 g*	2150
319	20.00	3.50	3.50	4.50	2.00	57.00	7.50	2.00	-	2830 g*	2300
320	20.00	3.50	3.50	4.50	2.00	56.00	8.50	2.00	-	2950 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$K0_{0.5}$	$Al0_{1.5}$	Tio_2	$Zr0_2$	Melting Temp. °F.	Liquidus Temp. °F.
321	20.00	3.50	3.50	4.50	2.00	55.00	2.00	9.50	2950 s	--
322	20.00	3.50	3.50	4.50	2.00	54.00	2.00	10.50	2950 s	--
323	20.00	3.50	3.50	4.50	2.00	53.00	2.00	11.50	2950 s	--
324	20.00	3.50	3.50	4.50	2.00	52.00	2.00	12.50	2950 s	--
325	20.00	3.50	3.50	4.50	2.00	51.00	2.00	13.50	2950 s	--
326	20.00	3.50	3.50	4.50	2.00	50.00	2.00	14.50	2950 s	--
327	20.00	3.50	3.50	3.50	2.00	49.00	2.00	15.50	2950 s	--
328	20.00	3.50	3.50	4.50	2.00	48.00	2.00	16.50	2950 s	--
329	20.00	3.50	3.50	4.50	2.00	47.00	2.00	17.50	2950 s	--
330	20.00	3.50	3.50	4.50	2.00	46.00	2.00	18.50	2950 s	--
331	20.00	3.50	3.50	4.50	2.00	45.00	2.00	19.50	2950 s	--
332	20.00	3.50	3.50	4.50	2.00	44.00	2.00	20.50	2950 s	--
333	31.12	3.54	1.77	6.85	2.00	53.13	1.59	-	2420 g*	1900
334	30.12	3.54	1.77	5.85	3.00	53.13	2.59	-	2650 g*	1900
335	31.12	3.54	0.77	6.85	2.00	53.13	2.59	-	2500 g*	2000
336	31.12	3.54	1.77	6.85	2.00	52.13	2.59	-	2500 g	1950
337	31.12	3.54	1.77	6.85	2.00	51.13	2.59	1.00	2425 g	2350
338	31.12	3.54	1.77	6.85	2.00	50.03	2.59	2.00	2550 g	2450
339	31.12	3.54	1.77	6.85	2.00	51.13	1.59	2.00	2570 g	1900
340	32.12	3.54	0.77	5.85	3.00	50.13	1.59	3.00	2680 g*	2240

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	TiO_2	ZrO_2	Melting Temp. °F.	Liquidus Temp. °F.
341	33.12	2.54	0.77	5.05	3.00	50.13	1.59	3.00	2740 g*	2240
342	32.12	2.54	0.77	5.85	3.00	50.13	1.59	4.00	2800 d	2050
343	31.12	2.54	0.77	5.85	3.00	50.13	1.59	5.00	2850 d	2700
345	30.12	3.54	1.77	7.85	2.00	51.13	1.59	2.00	2550 g	2350
346	30.12	3.04	1.27	7.85	3.00	51.13	1.59	2.00	2600 g	2400
347	31.12	3.04	1.27	7.85	3.00	50.13	1.59	2.00	2580 g	2350
348	31.12	3.04	1.27	7.85	3.00	49.13	1.59	3.00	2700 g*	2550
349	31.12	3.04	1.27	7.85	3.00	50.13	0.59	3.00	2800 g*	2550
350	31.12	3.04	1.77	7.85	3.00	49.13	1.09	3.00	2750 g*	2450
351	31.12	3.54	1.27	7.85	3.00	49.13	1.09	3.00	2950 d	--
352	30.12	3.54	1.27	8.85	3.00	49.13	1.09	4.00	2950 s	--
353	30.12	3.04	0.77	8.85	3.00	49.13	1.09	5.00	2950 s	--
354	31.12	3.04	0.77	8.85	3.00	48.13	1.09	5.00	2950 s	--
355	31.12	3.04	1.27	7.85	3.00	48.13	2.59	3.00	2950 d	--
356	31.12	3.04	1.27	7.85	3.00	48.63	2.09	3.00	2950 d	--
357	31.12	3.04	1.27	7.85	3.00	47.63	3.09	3.00	2950 d	--
358	30.62	3.04	1.77	7.85	3.00	49.13	1.59	3.00	2950 d	--
359	29.62	3.04	2.77	7.85	3.00	49.13	1.59	3.00	2950 d	--
360	30.62	3.54	1.27	7.85	3.00	49.13	1.59	3.00	2950 d	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	TiO_2	ZrO_2	Melting Temp. °F.	Liquidus Temp. °F.
361	29.62	4.54	1.27	7.85	3.00	49.13	1.59	3.00	2950 d	--
362	32.12	3.04	1.27	7.85	2.00	49.13	1.59	3.00	2950 d	--
363	33.12	3.04	1.27	6.85	2.00	49.13	1.59	3.00	2950 d	--
364	33.12	4.04	1.27	6.85	1.00	49.13	1.59	3.00	2950 d	--
365	33.12	4.04	2.27	6.35	0.50	49.13	1.59	3.00	2950 d	--
366	34.12	4.04	2.27	5.35	0.50	49.13	1.59	3.00	2950 d	--
367	35.12	4.04	2.27	4.35	0.50	49.13	1.59	3.00	2950 d	--
368	34.43	-	-	5.85	3.00	53.13	1.59	2.00	2650 g	2588
369	32.71	-	1.72	5.85	3.00	53.13	1.59	2.00	2640 g	2605
370	30.98	-	3.44	5.85	3.00	53.13	1.59	2.00	2620 g	2550
371	29.26	-	5.16	5.85	3.00	53.13	1.59	2.00	2650 d	--
372	27.54	-	6.87	5.85	3.00	53.13	1.59	2.00	2630 d	--
373	25.82	-	8.61	5.85	3.00	53.13	1.59	2.00	2880 d	--
374	24.10	-	10.33	5.85	3.00	53.13	1.59	2.00	2960 s	--
375	32.71	1.72	-	5.85	3.00	53.13	1.59	2.00	2620 g	2576
376	30.98	1.72	1.72	5.85	3.00	53.13	1.59	2.00	2600 g	2560
377	29.26	1.72	3.44	5.85	3.00	53.13	1.59	2.00	2570 g	2480
378	27.54	1.72	5.16	5.85	3.00	53.13	1.59	2.00	2580 d	--
379	25.82	1.72	6.87	5.85	3.00	53.13	1.59	2.00	2700 d	--
380	24.12	1.72	8.61	5.85	3.00	53.13	1.59	2.00	2900 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	TiO_2	ZrO_2	Melting Temp. °F.	Liquidus Temp. °F.
381	30.98	3.44	-	5.85	3.00	53.13	1.59	2.00	2580 g	2578
382	27.54	3.44	3.44	5.85	3.00	53.13	1.59	2.00	2600 g	2574
383	25.82	3.44	5.16	5.85	3.00	53.13	1.59	2.00	2600 d	--
384	24.10	3.44	6.87	5.85	3.00	53.13	1.59	2.00	2650 d	--
385	29.26	5.16	-	5.85	3.00	53.13	1.59	2.00	2600 g	--
386	27.54	5.16	1.72	5.85	3.00	53.13	1.59	2.00	2650 g	2550
387	25.82	5.16	3.44	5.85	3.00	53.13	1.59	2.00	2630 g	2550
388	24.10	5.16	5.16	5.85	3.00	53.13	1.59	2.00	2600 g	2630
389	27.54	6.87	-	5.85	3.00	53.13	1.59	2.00	2680 g	2570
390	25.82	6.87	1.72	5.85	3.00	53.13	1.59	2.00	2730 g	2580
391	24.10	6.87	3.44	5.85	3.00	53.13	1.59	2.00	2580 g	2568
392	25.82	8.61	-	5.85	3.00	53.13	1.59	2.00	2980 s	--
393	24.10	8.61	1.72	5.85	3.00	53.13	1.59	2.00	2900 s	--
394	24.10	10.33	-	5.85	3.00	53.13	1.59	2.00	2950 s	--
395	27.54	5.16	1.72	5.85	3.00	56.72	-	-	2900 g	2490
396	27.54	5.16	1.72	5.85	3.00	55.58	-	1.13	2900 g	2465
397	27.54	5.16	1.72	5.85	3.00	54.45	-	2.27	2900 g	2550
398	27.54	5.16	1.72	5.85	3.00	53.32	-	3.40	2900 s	2750
399	27.54	5.16	1.72	5.85	3.00	52.18	-	4.54	2900 s	2750
400	27.54	5.16	1.72	5.85	3.00	51.05	-	5.67	2900 s	2750

TABLE I (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	TiO_2	ZrO_2	Melting Temp. °F.	Liquidus Temp. °F.
401	21.54	5.16	1.72	5.85	3.00	55.59	1.13	-	2900 g	2495
402	27.54	5.16	1.72	5.85	3.00	54.45	1.13	1.13	2900 g	2445
403	27.54	5.16	1.72	5.85	3.00	53.32	1.13	2.27	2900 g	2550
404	27.54	5.16	1.72	5.85	3.00	52.18	1.13	3.40	2900 s	2750
405	27.54	5.1[illegible]	1.72	5.05	3.00	51.05	1.13	4.54	2900 s	2750
406	27.54	5.16	1.72	5.85	3.00	54.45	2.27	-	2900 g	2467
407	27.54	5.16	1.72	5.85	3.00	53.32	2.27	1.13	2900 g	2480
408	27.54	5.16	1.72	5.85	3.00	52.18	2.27	2.27	2900 g	2515
409	27.54	5.16	1.72	5.85	3.00	51.05	2.27	3.40	2900 s	--
410	27.54	5.16	1.72	5.85	3.00	53.32	3.40	-	2900 d	--
411	27.54	5.16	1.72	5.85	3.00	52.18	3.40	1.13	2900 d	--
412	27.54	5.16	1.72	5.85	3.00	51.05	3.40	2.27	2900 d	--
413	27.54	5.16	1.72	5.85	3.00	52.18	4.54	-	2900 d	--
414	27.54	5.16	1.72	5.85	3.00	51.05	4.54	1.13	2900 d	--
415	27.54	5.16	1.72	5.85	3.00	51.05	5.67	-	2900 d	--
416	27.54	5.16	1.72	5.85	3.00	48.78	-	7.94	2900 s	--
417	27.54	5.16	1.72	5.85	3.00	46.51	-	10.21	2900 s	--
418	27.54	5.16	1.72	5.85	3.00	48.78	2.27	5.67	2900 s	--
419	27.54	5.16	1.72	5.85	3.00	46.51	2.27	7.94	2900 s	--
420	27.54	5.16	1.72	5.85	3.00	46.51	4.54	5.67	2900 d	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$K0_{0.5}$	$Al0_{1.5}$	$Ti0_2$	$Zr0_2$	Melting Temp. °F.	Liquidus Temp. °F.
421	27.54	5.16	1.72	5.85	3.00	46.51	4.54	5.67	2900 s	--
422	27.54	5.16	1.72	5.85	3.00	48.78	6.80	1.13	2900 d	--
423	27.54	5.16	1.72	5.85	3.00	46.51	6.80	3.40	2900 s	--
424	27.54	5.16	1.72	5.85	3.00	48.78	7.94	-	2900 d	--
425	27.54	5.16	1.72	5.85	3.00	45.38	7.94	3.40	2900 s	--
426	27.54	5.16	1.72	5.85	3.00	46.51	10.21	-	2900 s	--
427	28.00	5.25	1.75	7.27	3.73	51.84	1.08	1.08	2900 g	2455
428	29.60	5.55	1.85	6.05	3.05	51.84	1.08	1.08	2900 g	2468
429	29.60	5.55	1.85	4.63	2.35	53.76	1.12	1.12	2900 g	2440
430	28.00	5.25	1.75	4.63	2.37	55.68	1.16	1.16	2900 d	--
431	26.40	4.95	1.65	6.05	3.05	55.68	1.16	1.16	2900 d	2500
432	26.40	4.95	1.65	7.27	3.73	53.76	1.12	1.12	2900 g	2430
433	28.00	5.25	1.75	8.59	4.41	49.92	1.04	1.04	2900 g	2500
434	29.60	5.55	1.85	7.27	3.73	49.92	1.04	1.04	2900 g	2490
435	31.20	5.85	1.95	6.05	3.05	49.92	1.04	1.04	2900 g	2535
436	31.20	5.85	1.95	4.63	2.37	51.84	1.08	1.08	2900 g	2530
437	31.20	5.85	1.95	3.30	1.70	53.76	1.12	1.12	2900 g	2486
438	29.60	5.55	1.85	3.30	1.70	55.68	1.16	1.16	2900 g	2508
439	28.00	5.25	1.75	3.30	1.70	57.60	1.20	1.20	2900 d	--
440	26.40	4.95	1.65	4.63	2.37	57.60	1.20	1.20	2900 d	---

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$Ka0_{0.5}$	$Al0_{1.5}$	$Ti0_2$	$Zr0_2$	$Li0_{0.5}$	Melting Temp.°F.	Liquidus Temp°F.
441	24.80	4.65	1.55	6.05	3.05	57.60	1.20	1.20	-	2900 d	--
442	24.80	4.65	1.55	7.27	3.73	55.68	1.16	1.16	-	2900 d	--
443	24.80	4.65	1.55	8.59	4.41	53.76	1.12	1.12	-	2900 d	--
444	26.40	4.95	1.65	8.59	4.41	51.84	1.08	1.08	-	2900 d	--
445	26.40	4.95	1.65	9.00	1.00	53.76	1.12	1.12	-	2900 g	2465
446	26.40	4.95	1.65	5.00	5.00	53.76	1.12	1.12	-	2900 g	2430
447	26.40	4.95	1.65	3.00	7.00	53.76	1.12	1.12	-	2900 g	2458
448	26.40	4.95	1.65	1.00	9.00	53.76	1.12	1.12	-	2900 g	2525
449	26.40	4.95	1.65	8.00	-	53.76	1.12	1.12	2.00	2900 g	2448
450	26.40	4.95	1.65	6.00	2.00	53.76	1.12	1.12	2.00	2900 g	2430
451	26.40	4.95	1.65	4.00	4.00	53.76	1.12	1.12	2.00	2900 g	2408
452	26.40	4.95	1.65	2.00	6.00	53.76	1.12	1.12	2.00	2900 g	2422
453	26.40	4.95	1.65	-	8.00	53.76	1.12	1.12	2.00	2900 g	2460
454	26.40	4.95	1.65	6.00	-	53.76	1.12	1.12	4.00	2900 g	2415
455	26.40	4.95	1.65	4.00	2.00	53.76	1.12	1.12	4.00	2900 g	2435
456	26.40	4.95	1.65	2.00	4.00	53.76	1.12	1.12	4.00	2900 g	2428
457	26.40	4.95	1.65	-	6.00	53.76	1.12	1.12	4.00	2900 g	2405
458	26.40	4.95	1.65	4.00	-	53.76	1.12	1.12	6.00	2900 g	2360
459	26.40	4.95	1.65	2.00	2.00	53.76	1.12	1.12	6.00	2900 g	2380
460	26.40	4.95	1.65	-	4.00	53.76	1.12	1.12	6.00	2900 g	2402

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KaO_{0.5}$	$AlO_{1.5}$	TiO_2	ZrO_2	$LiO_{0.5}$	SiO_2	$BO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
461	26.40	4.95	1.65	2.00	-	53.76	1.12	1.12	8.00	-	-	2900 g*	--
462	26.40	4.95	1.65	1.00	1.00	53.76	1.12	1.12	8.00	-	-	2900 g*	--
463	26.40	4.95	1.65	-	2.00	53.76	1.12	1.12	8.00	-	-	2900 g*	--
464	27.54	5.16	1.72	5.85	3.00	55.59				1.13	-	2900 g*	2440
465	27.54	5.16	1.72	5.85	3.00	54.45				2.27	-	2900 g	2417
466	27.54	5.16	1.72	5.85	3.00	53.32				3.40	-	2900 g	2427
467	27.54	5.16	1.72	5.85	3.00	52.18				4.54	-	2900 g	2406
468	27.54	5.16	1.72	5.85	3.00	51.05				5.67	-	2900 g	2463
469	27.54	5.16	1.72	5.85	3.00	55.59				-	1.13	2900 g	2450
470	27.54	5.16	1.72	5.85	3.00	54.45				1.13	1.13	2900 g	2470
471	27.54	5.16	1.72	5.85	3.00	53.32				2.27	1.13	2900 g	2448
472	27.54	5.16	1.72	5.85	3.00	52.18				3.40	1.13	2900 g	2371
473	27.54	5.16	1.72	5.85	3.00	51.05				4.54	1.13	2900 g	2338
474	27.54	5.16	1.72	5.85	3.00	54.45				-	2.27	2900 g	2445
475	27.54	5.16	1.72	5.85	3.00	53.32				1.13	2.27	2900 g	2380
476	27.54	5.16	1.72	5.85	3.00	52.18				2.27	2.27	2900 g	2409
477	27.54	5.16	1.72	5.85	3.00	51.05				3.40	2.27	2900 g	2382
478	27.54	5.16	1.72	5.85	3.00	53.32				-	3.40	2900 g	2423
479	27.54	5.16	1.72	5.85	3.00	52.18				1.13	3.40	2900 g	2389
480	27.54	5.16	1.72	5.85	3.00	51.05				2.27	3.40	2900 g	2396
481	27.54	5.16	1.72	5.85	3.00	52.18				-	4.54	were not melted	
482	27.54	5.16	1.72	5.85	3.00	51.05				1.13	4.54	were not melted	

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	TiO_2	ZrO_2	$LiO_{0.5}$	$BO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
483	27.54	5.16	1.72	5.85	3.00	51.05	-	-	-	5.67	were	not melted
484	27.06	3.96	1.98	4.40	4.40	53.76	1.12	1,12	2.20	-	2900 g	2388
485	26.40	3.96	2.64	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2388
486	27.06	4.62	1.32	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2398
487	26.40	4.62	1.98	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2390
488	25.74	4.62	2.64	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2390
489	27.06	5.28	0.66	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2400
490	26.40	5.28	1.32	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2413
491	25.74	5.28	1.98	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2406
492	25.08	5.28	2.64	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2365
493	26.40	5.94	0.66	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2400
494	25.74	5.94	1.32	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2398
495	25.08	5.94	1.98	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2375
496	28.38	3.96	0.66	4.40	4.40	53.76	1.12	1.12	2.20		2900 g	2406
497	25.08	3.96	3.96	4.40	4.40	53.76	1.12	1.12	2.20		2900 g*	2380
498	25.08	7.26	0.66	4.40	4.40	53.76	1.12	1.12	2.20		2900 g*	2411
499	23.10	6.60	3.30	4.40	4.40	53.76	1.12	1.12	2.20		2900 g*	2390
500	23.10	9.24	0.66	4.40	4.40	53.76	1.12	1.12	2.20		2900 g*	2390
501	23.10	3.96	5.94	4.40	4.40	53.76	1.12	1.12	2.20		2900 g*	2370

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	BeO	Melting Temp. °F.	Liquidus Temp. °F.
502	27.54	5.16	1.72	5.85	3.00	49.91	6.81	-	-	2900 g	2345
503	27.54	5.16	1.72	5.85	3.00	48.78	7.94	-	-	2900 g	2338
504	27.54	5.16	1.72	5.85	3.00	47.64	9.08	-	-	2900 g	2358
505	27.54	5.16	1.72	5.85	3.00	49.91	5.67	1.13	-	2900 g	2332
505-B	24.71	5.16	1.72	5.85	3.00	49.91	5.67	1.13	2.83	- g	-
506	27.54	5.16	1.72	5.85	3.00	48.78	6.81	1.13	-	2900 g	2325
506-B	24.14	5.16	1.72	5.85	3.00	48.78	6.81	1.13	3.40	- g	-
507	27.54	5.16	1.72	5.85	3.00	47.64	7.94	1.13	-	2900 g	2325
507-B	23.57	5.16	1.72	5.85	3.00	47.64	7.94	1.13	3.97	- g	-
508	27.54	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	2900 g	2438
508-B	23.00	5.16	1.72	5.85	3.00	46.51	9.08	1.13	4.54	- g	-
509	27.54	5.16	1.72	5.85	3.00	45.38	10.21	1.13	-	2900 g	2445
509-B	22.44	5.16	1.72	5.85	3.00	45.38	10.21	1.13	5.10	- g	-
510	27.54	5.16	1.72	5.85	3.00	49.91	4.54	2.27	-	2900 g	2302
511	27.54	5.16	1.72	5.85	3.00	48.78	5.67	2.27	-	2900 g	2290
512	27.54	5.16	1.72	5.85	3.00	47.64	6.81	2.27	-	2900 g	2330
513	27.54	5.16	1.72	5.85	3.00	46.51	7.94	2.27	-	2900 g	2330
514	27.54	5.16	1.72	5.85	3.00	45.38	9.08	2.27	-	2900 g	2340
515	24.79	5.16	1.72	5.85	3.00	46.51	9.08	1.12	ZnO 2.75	2900 d	2750

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	ZrO_2	PbO	ZnO	Melting Temp. °F.	Liquidus Temp. °F.
516	22.03	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	-	5.51	2900 d	2850
517	19.28	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	-	8.26	2900 d	2850
518	16.52	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	-	11.02	2900 s	--
519	13.77	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	-	13.77	2900 s	--
520	11.02	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	-	16.52	2900 s	--
521	24.79	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	2.75	-	2900 d	2750
522	22.03	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	2.75	2.75	2900 d	2850
523	19.28	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	2.75	5.51	2900 d	2850
524	16.52	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	2.75	8.26	2900 d	--
525	13.77	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	2.75	11.02	2900 dm	--
526	11.02	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	2.75	13.77	2900 dm	--
527	22.03	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	5.51	-	2900 dm	--
528	19.28	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	5.51	2.75	2900 dm	--
529	16.52	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	5.51	5.51	2900 dm	--
530	13.77	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	5.51	8.26	2900 dm	--
531	11.02	5.16	1.72	5.85	3.00	46.51	9.08	1.13	-	5.51	11.02	2900 dm	--
										$LiO_{0.5}$	CaF_2		
532	12.54	5.28	2.64	4.40	4.40	56.00	-	-	-	4.40	12.54	2900 d	--
533	12.54	5.28	2.64	4.40	4.40	54.88	-	-	1.12	4.40	12.54	2900 d	--
534	12.54	5.28	2.64	4.40	4.40	53.76	-	-	2.24	4.40	12.54	2900 d	--
535	12.54	5.28	2.64	4.40	4.40	52.64	-	-	3.36	4.40	12.54	2900 d	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	$LiO_{0.5}$	TiO_2	ZrO_2	CaF_2	Melting Temp. °F.	Liquidus Temp. °F.
536	12.54	5.28	2.64	4.40	4.40	51.52	4.40	-	4.48	12.54	2900 g*	--
537	12.54	5.28	2.64	4.40	4.40	50.40	4.40	-	5.60	12.54	2900 g*	--
538	12.54	5.28	2.64	4.40	4.40	54.88	4.40	1.12	-	12.54	2900 d	--
539	12.54	5.28	2.64	4.40	4.40	52.64	4.40	1.12	2.24	12.54	2900 d	--
540	12.54	5.28	2.64	4.40	4.40	51.52	4.40	1.12	3.36	12.54	2900 d	--
541	12.54	5.28	2.64	4.40	4.40	50.40	4.40	1.12	4.48	12.54	2900 g*	--
542	12.54	5.28	2.64	4.40	4.40	53.76	4.40	2.24	-	12.54	2900 d	--
543	12.54	5.28	2.64	4.40	4.40	52.64	4.40	2.24	1.12	12.54	2900 d	--
544	12.54	5.28	2.64	4.40	4.40	51.52	4.40	2.24	2.24	12.54	2900 d	---
545	12.54	5.28	2.64	4.40	4.40	50.40	2.20	2.24	3.36	12.54	2900 d	--
546	12.54	5.28	2.64	4.40	4.40	52.64	2.20	3.36	-	12.54	2900 d	--
547	12.54	5.28	2.64	4.40	4.40	51.52	2.20	3.36	1.12	12.54	2900 d	--
548	12.54	5.28	2.64	4.40	4.40	50.40	2.20	3.36	2.24	12.54	2900 d	--
549	12.54	5.28	2.64	4.40	4.40	51.52	2.20	4.48	-	12.54	2900 d	--
550	12.54	5.28	2.64	4.40	4.40	50.40	2.20	4.48	1.12	12.54	2900 d	--
551	12.54	5.28	2.64	4.40	4.40	50.40	2.20	5.60	-	12.54	2900 d	--
							SiO_2	$BO_{1.5}$	ZnO			
552	8.26	5.16	1.72	5.85	3.00	46.51	9.08	1.13	19.28		2900 s	--
553	5.51	5.16	1.72	5.85	3.00	46.51	9.08	1.13	22.03		2900 s	--
554	2.75	5.16	1.72	5.85	3.00	46.51	9.08	1.13	24.79		2900 s	--
555		5.16	1.72	5.85	3.00	46.51	9.08	1.13	27.54		2900 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	ZnO	Melting Temp. °F.	Liquidus Temp. °F.
552	9.81	1.72	-	5.85	3.00	47.64	7.94	1.13	22.89	2900 s	--
553	9.29	1.72	1.72	5.85	3.00	47.64	7.94	1.13	21.69	2900 s	--
554	8.78	1.72	3.44	5.85	3.00	47.64	7.94	1.13	20.48	2900 s	--
555	8.26	1.72	5.16	5.85	3.00	47.64	7.94	1.13	19.28	2900 s	--
556	7.75	1.72	6.88	5.85	3.00	47.64	7.94	1.13	18.07	2900 s	--
557	7.23	1.72	8.60	5.85	3.00	47.64	7.94	1.13	16.86	2900 s	--
558	6.71	1.72	10.33	5.85	3.00	47.64	7.94	1.13	15.66	2900 s	--
559	6.20	1.72	12.05	5.85	3.00	47.64	7.94	1.13	14.46	2900 s	--
560	5.68	1.72	13.77	5.85	3.00	47.64	7.94	1.13	13.25	2900 s	--
561	5.16	1.72	15.49	5.85	3.00	47.64	5.94	1.13	12.04	2900 s	--
562	9.29	3.44	-	5.85	3.00	47.64	7.94	1.13	21.69	2900 s	--
563	8.78	3.44	1.72	5.85	3.00	47.64	7.94	1.13	20.48	2900 s	--
564	8.26	3.44	3.44	5.85	3.00	47.64	7.94	1.13	19.28	2900 s	--
565	7.75	3.44	5.16	5.85	3.00	47.64	7.94	1.13	18.07	2900 s	--
566	7.23	3.44	6.88	5.85	3.00	47.64	7.94	1.13	16.86	2900 s	--
567	6.71	3.44	8.60	5.85	3.00	47.64	7.94	1.13	15.66	2900 s	--
568	6.20	3.44	10.33	5.85	3.00	47.64	7.94	1.13	14.46	2900 s	--
569	5.68	3.44	12.05	5.85	3.00	47.64	7.94	1.13	13.25	2900 s	--
570	5.16	3.44	13.77	5.85	3.00	47.64	7.94	1.13	12.04	2900 s	--
571	8.78	5.16	-	5.85	3.00	47.64	7.94	1.13	20.48	2900 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$K0_{0.5}$	$Al0_{1.5}$	$Si0_2$	$B0_{1.5}$	Zn0	Melting Temp. °F.	Liquidus Temp. °F.
572	8.26	5.16	1.72	5.85	3.00	47.64	7.94	1.13	19.28	2900 s	--
573	7.75	5.16	3.44	5.85	3.00	47.64	7.94	1.13	13.25	2900 s	--
570	5.16	3.44	13.77	5.85	3.00	47.64	7.94	1.13	12.04	2900 s	--
571	8.78	5.16	-	5.85	3.00	47.64	7.94	1.13	20.48	2900 s	--
572	8.26	5.16	1.72	5.85	3.00	47.64	7.94	1.13	19.28	2900 s	--
573	7.75	5.16	3.44	5.85	3.00	47.64	7.94	1.13	18.07	2900 s	--
574	7.23	5.16	5.16	5.85	3.00	47.64	7.94	1.13	16.86	2900 s	--
575	6.71	5.16	6.88	5.85	3.00	47.64	7.94	1.13	15.66	2900 s	--
576	6.20	5.16	8.60	5.85	3.00	47.64	7.94	1.13	14.46	2900 s	--
577	5.68	5.16	10.33	5.85	3.00	47.64	7.94	1.13	13.25	2900 s	--
578	5.16	5.16	12.05	5.85	3.00	47.64	7.94	1.13	12.04	2900 s	--
579	8.26	6.88	-	5.85	3.00	47.64	7.94	1.13	19.28	2900 s	--
580	7.75	6.88	1.72	5.85	3.00	47.64	7.94	1.13	18.07	2900 s	--
581	7.23	6.88	3.44	5.85	3.00	47.64	7.94	1.13	16.86	2900 s	--
582	6.71	6.88	5.16	5.85	3.00	47.64	7.94	1.13	15.66	2900 s	--
583	6.20	6.88	6.88	5.85	3.00	47.64	7.94	1.13	14.46	2900 s	--
584	5.68	6.88	8.60	5.85	3.00	47.64	7.94	1.13	13.25	2900 s	--
585	5.16	6.88	10.33	5.85	3.00	47.64	7.94	1.13	12.04	2900 s	--
586	7.75	8.60	-	5.85	3.00	47.64	7.94	1.13	18.07	2900 s	--
587	7.23	8.60	1.72	5.85	3.00	47.64	7.94	1.13	16.86	2900 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$K0_{0.5}$	$Al0_{1.5}$	$Si0_2$	$B0_{1.5}$	Zn0	Melting Temp. °F.	Liquidus Temp. °F.
588	6.71	8.60	3.44	5.85	3.00	47.64	7.94	1.13	15.66	2900 s	--
589	6.20	8.60	5.16	5.85	3.00	47.64	7.94	1.13	14.46	2900 s	--
590	5.68	8.60	6.88	5.85	3.00	47.64	7.94	1.13	13.25	2900 s	--
591	5.16	8.60	8.60	5.85	3.00	47.64	7.94	1.13	12.04	2900 s	--
592	6.30	6.00	3.00	3.31	1.70	54.60	9.10	1.30	14.70	2900 s	--
593	7.35	7.00	3.50	3.31	1.70	50.40	8.40	1.20	17.15	2900 s	--
594	8.40	8.00	4.00	3.31	1.70	46.20	7.70	1.10	19.60	2900 s	--
595	9.45	9.00	4.50	3.31	1.70	42.00	7.00	1.00	22.05	2900 s	--
596	10.50	10.00	5.00	3.31	1.70	37.80	6.30	0.90	24.50	2900 s	--
597	11.55	11.00	5.50	3.31	1.70	33.60	5.60	0.80	26.95	2900 s	--
598	5.78	5.50	2.75	4.96	2.54	54.60	9.10	1.30	13.48	2900 s	--
599	6.83	6.50	3.25	4.96	2.54	50.40	8.40	1.20	15.93	2900 s	--
600	7.88	7.50	3.75	4.96	2.54	46.20	7.70	1.10	18.38	2900 s	--
601	8.93	8.50	4.25	4.96	2.54	42.00	7.00	1.00	20.83	2900 s	--
602	9.98	9.50	4.75	4.96	2.54	37.80	6.30	0.90	23.28	2900 s	--
603	11.03	10.50	5.25	4.96	2.54	33.60	5.60	0.80	25.73	2900 s	--
604	5.25	5.00	2.50	6.61	3.39	54.60	9.10	1.30	12.25	2900 s	--
605	6.30	6.00	3.00	6.61	3.30	50.40	8.40	1.20	14.70	2900 s	--
606	7.35	7.00	3.50	6.61	3.39	46.20	7.70	1.10	17.15	2900 s	--
607	8.40	8.00	4.00	6.61	3.39	42.00	7.00	1.00	19.00	2900 s	--

TABLE I. (Cont.)

EXPLORATORY CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	ZnO	Melting Temp. °F.	Liquidus Temp. °F.
608	9.45	9.00	4.50	6.61	3.39	37.80	6.30	0.90	22.05	2900 s	--
609	10.50	10.00	5.00	6.61	3.39	33.60	5.60	0.80	24.50	2900 s	--
610	4.73	4.50	2.25	8.26	4.24	54.60	9.10	1.30	11.03	2900 s	--
611	5.78	5.50	2.75	8.26	4.24	50.40	8.40	1.20	13.48	2900 s	--
612	6.83	6.50	3.25	8.26	4.24	46.20	7.70	1.10	15.93	2900 s	--
613	7.88	7.50	3.75	8.26	4.24	42.00	7.00	1.00	18.38	2900 s	--
614	8.93	8.50	4.25	8.26	4.24	37.80	6.30	0.90	20.83	2900 s	--
615	9.98	9.50	4.75	8.26	4.24	33.60	5.60	0.80	23.28	2900 s	--
616	4.20	4.00	2.00	9.92	5.09	54.60	9.10	1.30	9.80	2900 s	--
617	5.25	5.00	2.50	9.92	5.09	50.40	8.40	1.20	12.25	2900 s	--
618	6.30	6.00	3.00	9.92	5.09	46.20	7.70	1.10	14.70	2900 s	--
619	7.35	7.00	3.50	9.92	5.09	42.00	7.00	1.00	17.15	2900 s	--
620	8.40	8.00	4.00	9.92	5.09	37.80	6.30	0.90	;9.60	2900 s	--
621	9.45	9.00	4.50	9.92	5.09	33.60	5.60	0.80	22.05	2900 s	--
622	4.73	4.50	2.75	11.57	5.93	50.40	8.40	1.20	11.03	2900 s	--
623	5.78	5.50	2.75	11.57	5.93	46.20	7.70	1.10	13.48	2900 s	--
624	6.83	6.50	3.25	11.57	5.93	42.00	7.00	1.00	15.93	2900 s	--
625	7.88	7.50	3.75	11.57	5.93	37.80	6.30	0.90	18.38	2900 s	--
626	8.93	8.50	4.25	11.57	5.93	33.60	5.60	0.80	20.83	2900 s	--
627	4.20	4.00	2.00	13.22	6.78	50.40	8.40	1.20	9.80	2900 s	--

TABLE I (Cont.)

EXPLORATORY CALCIUM ALUMINA LASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	ZnO	Melting Temp. °F.	Liquidus Temp. °F.
628	5.25	5.00	2.50	13.22	6.78	46.20	7.70	1.10	12.25	2900 s	--
629	6.30	6.00	3.00	13.22	6.78	42.00	7.00	1.00	14.70	2900 s	--
630	7.35	7.00	3.50	13.22	6.78	37.80	6.30	0.90	17.15	2900 s	--
631	8.40	8.00	4.00	13.22	6.78	33.60	5.60	0.80	19.60	2900 s	--

TABLE II.

PHYSICAL PROPERTIES OF EXPLORATORY CALCIUM ALUMINATE GLASSES

Glass No.	log. viscosity in poises 0.5 °F.	1.00 °F.	1.50 °F.	2.0 °F.	Specific Gravity gm/ml	$Ex10^{-6}$ psi
67	2825	2575	2380	-	-	-
166	2725	2500	2340	-	3.09	16.1
197	-	-	-	-	3.19	16.7
211	-	-	-	-	3.198	16.4
310	-	2610	2430	-	-	-
313	-	2645	2475	-	-	-
314	-	2650	2570	-	-	-
336	-	2625	-	-	-	-
339	-	2615	2450	-	-	-
395	-	2730	2525	-	2.91	15.85
451	-	2675	2480	2350	-	-
472	-	-	2520	2380	-	-
492	-	2680	2480	2390	-	-
506	-	2700	2515	2368	-	-
508	-	2675	2485	2332	2.91	15.42
511	-	2680	2495	2348	-	-
505-B	-	2705	2525	2390	2.89	15.85
506-B	- Not determined-					
507-B	-	2645	2460	2330	2.90	15.79
508-B	-Not determined-					
509-B	-	2700	2515	2370	2.89	15.76

Small changes in composition were made to outline the areas of glass formation in the calcium aluminate system. All the compositions shown in Table III were melted in small platinum crucibles for this purpose. Large melts of 1500 grams were prepared for physical property measurements. The results of liquidus temperature measurements, Appendix I, viscosity measurements, Appendix II, and Young's modulus measurements, Appendix V for selected compositions of this group are shown in Table IV, page 59. The letter "g" beside the melting temperature in Table III indicates that clear glass was produced in a 10 gram melt of the composition. The letter "d" beside the melting temperature signifies devitrification of a 10 gram melt. These melts were removed from the furnace at the melting temperature and cooled in air. No quenching of the crucible of glass was done. All melting was done in platinum crucibles in a gas fired muffle furnace at temperatures of 2750°F. to 2900°F.

Compositions starting with No. 632 were those which were investigated after the beginning of this contract. These compositions were designed to determine the extent of glass formation in the calcium aluminate system containing small quantities of other alkaline earth oxides, BeO, MgO and BaO; alkaline oxides, Na_2O, K_2O and Li_2O; other acidic components, SiO_2, B_2O_3, TiO_2 and ZrO_2. Small quantities of iron oxide were investigated in a few compositions. The effect of variations of these components on the physical properties of the glass was determined.

Compositions Nos. 632 - 652 were a study of the substitution of MgO and BaO for CaO in glass No. 508. The replacement of CaO by either MgO or BaO up to 20% of the total alkaline earth oxides resulted in clear glasses. Substitutions of more than 20% by either MgO or BaO resulted in melts which devitrified on cooling.

Compositions Nos. 653 - 671 were a study of the substitution of $BO_{1.5}$ and SiO_2 for $AlO_{1.5}$ in glass No. 508. Substitutions up to 50% of the total acidic components by $BO_{1.5}$ and SiO_2 resulted in clear glasses.

Compositions Nos. 672 - 692 were a study of the substitution of $KO_{0.5}$ and $LiO_{0.5}$ for $NaO_{0.5}$ in glass No. 508. Clear glasses were found for 100% substitution of $NaO_{0.5}$ by $KO_{0.5}$ and $LiO_{0.5}$.

Compositions Nos. 693 - 712 were a systematic variation of the three major groups. The acidic group was composed of $AlO_{1.5}$, SiO_2 and $BO_{1.5}$. The alkali oxide group was composed of CaO, MgO and BaO. The ratio of $AlO_{1.5}$:SiO_2:$BO_{1.5}$ was 6:2:2. The ratio of $NaO_{0.5}$:$KO_{0.5}$:$LiO_{0.5}$ was 4:4:2. The ratio of CaO:MgO:BaO was 6:2:2. Glasses were formed of all compositions containing 45% or more acidic components. The glasses containing 45 - 50% acidic components were blue to green in color. The glasses containing more than 50% acidic components were colorless.

Compositions Nos. 713 - 730 were a systematic variation of the major groups with a ratio of $AlO_{1.5}:SiO_2:BO_{1.5}$ of 6:2:2; a ratio of $NaO_{0.5}:KO_{0.5}:LiO_{0.5}$ of 4:4:2 and a ratio of CaO:MgO:BaO of 4:1:0. All compositions containing 50% or more acidic components formed clear glasses. Only composition No. 720 formed a clear glass containing less than 50% acidic components.

Compositions Nos. 731 - 751 were a systematic variation of the major groups with a ratio of $AlO_{1.5}:SiO_2:BO_{1.5}$ of 6:0:4; a ratio of $NaO_{0.5}:KO_{0.5}:LiO_{0.5}$ of 4:4:2 and a ratio of CaO:MgO:BaO of 4:1:0. All compositions containing 45% or more acidic components formed clear glasses without devitrification.

Compositions Nos. 752 - 772 were a systematic variation of the major groups with a $AlO_{1.5}:SiO_2:BO_{1.5}$ ratio of 6:4:0; a $NaO_{0.5}:KO_{0.5}:LiO_{0.5}$ ratio of 4:4:2, and a CaO:MgO:BaO ratio of 4:1:0. All compositions containing 50% or more acidic components and composition No. 767 formed clear glasses without devitrification.

Compositions Nos. 773 - 792 were a systematic variation of the major groups with a $AlO_{1.5}:SiO_2:BO_{1.5}$ ratio of 6:2:2; a $NaO_{0.5}:KO_{0.5}:LiO_{0.5}$ ratio of 2:4:4 and a CaO:MgO:BaO ratio of 4:1:0. All compositions containing 50% or more acidic components formed clear glasses.

Compositions Nos. 792 - 812 were a systematic variation of the major groups. The $AlO_{1.5}:SiO_2:BO_{1.5}$ ratio was 6:2:2. The $NaO_{0.5}:KO_{0.5}:LiO_{0.5}$ ratio was 4:2:4. The CaO:MgO:BaO ratio was 4:1:0. all glasses, except No. 808, which contained 45% acidic components formed clear glasses.

Compositions Nos. 813 - 833 were a systematic variation of the major groups. The $AlO_{1.5}:SiO_2:BO_{1.5}$ ratio was 6:2:2. The $NaO_{0.5}:KO_{0.5}:LiO_{0.5}$ ratio was 4:4:2 and the CaO:MgO:BaO ratio was 4:0:1. All glasses containing 50% acidic components and No. 814 formed clear glasses.

Compositions Nos. 834 - 851 were mixed but never melted because of the high toxicity of BeO (5, 6) which was one of the constituents.

Compositions Nos. 852 - 861 were substitutions of one constituent for another in an attempt to find a glass which had a low liquidus temperature and greater viscosity.

Compositions Nos. 862 - 891 were substitutions of $FeO_{1.5}$ for all other constituents in an attempt to lower liquidus temperatures. No glasses were produced in this entire series.

Compositions 892 - 949 were the final attempts to add TiO_2 and ZrO_2 to these compositions. High liquidus temperatures, high melting temperatures and low viscosities were found in nearly all these melts.

TABLE III.

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
632	34.42	-	-	5.85	3.00	46.51	9.08	1.13	2900 g	2460
633	27.53	-	6.88	5.85	3.00	46.51	9.08	1.13	2900 g	2460
634	20.65	-	13.77	5.85	3.00	46.51	9.08	1.13	2900 d	--
635	13.77	-	20.65	5.85	3.00	46.51	9.08	1.13	2900 d	--
636	6.88	-	27.53	5.85	3.00	46.51	9.08	1.13	2900 d	--
637	-	-	34.42	5.85	3.00	46.51	9.08	1.13	2900 d	--
638	27.53	6.88	-	5.85	3.00	46.51	9.08	1.13	2900 g	2691
639	20.65	6.88	6.88	5.85	3.00	46.51	9.08	1.13	2900 g	2640
640	13.77	6.88	13.77	5.85	3.00	46.51	9.08	1.13	2900 d	--
641	6.88	6.88	20.65	5.85	3.00	46.51	9.08	1.13	2900 d	--
642	-	6.88	27.53	5.85	3.00	46.51	9.08	1.13	2900 d	--
643	20.65	13.77	-	5.85	3.00	46.51	9.08	1.13	2900 d	--
644	13.77	13.77	6.88	5.85	3.00	46.51	9.08	1.13	2900 d	--
645	6.88	13.77	13.77	5.85	3.00	46.51	9.08	1.13	2900 d	--
646	-	13.77	20.65	5.85	3.00	46.51	9.08	1.13	2900 d	--
647	13.77	20.65	-	5.85	3.00	46.51	9.08	1.13	2900 d	--
648	6.88	20.65	6.88	5.85	3.00	46.51	9.08	1.13	2900 d	--
649	-	20.65	13.77	5.85	3.00	46.51	9.08	1.13	2900 d	--
650	6.88	27.53	-	5.85	3.00	46.51	9.08	1.13	2900 d	--

TABLE III. (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$K0_{0.5}$	$Al0_{1.5}$	$Si0_2$	$B0_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
651	-	27.53	6.88	5.85	3.00	46.51	9.08	1.13	2900 d	--
652	-	34.42	-	5.85	3.00	46.51	9.08	1.13	2900 d	--
653	27.54	5.16	1.72	5.85	3.00	45.38	11.34	-	2900 g	2560
654	27.54	5.16	1.72	5.85	3.00	39.70	17.02	-	2900 g	--
655	27.54	5.16	1.72	5.85	3.00	34.03	22.69	-	2900 g	--
656	27.54	5.16	1.72	5.85	3.00	28.36	28.36	-	2900 g	2580
657	27.54	5.16	1.72	5.85	3.00	51.05	-	5.67	2900 g	2487
658	27.54	5.16	1.72	5.85	3.00	45.38	5.67	5.67	2900 g	--
659	27.54	5.16	1.72	5.85	3.00	39.70	11.34	5.67	2900 g	2440
660	27.54	5.16	1.72	5.85	3.00	34.03	17.02	5.67	2900 g	--
661	27.54	5.16	1.72	5.85	3.00	28.36	22.69	5.67	2900 g	2560
662	27.54	5.16	1.72	5.85	3.00	45.38	-	11.34	2900 g	2465
663	27.54	5.16	1.72	5.85	3.00	39.70	5.67	11.34	2900 g	--
664	27.54	5.16	1.72	5.85	3.00	34.03	11.34	11.34	2900 g	2450
665	27.54	5.16	1.72	5.85	3.00	28.36	17.02	11.34	2900 g	--
666	27.54	5.16	1.72	5.85	3.00	39.70	-	17.02	2900 g	2300
667	27.54	5.16	1.72	5.85	3.00	34.03	5.67	17.02	2900 g	--
668	27.54	5.16	1.72	5.85	3.00	28.36	11.34	17.02	2900 g	--
669	27.54	5.16	1.72	5.85	3.00	34.03	-	22.69	2900 g	--
670	27.54	5.16	1.72	5.85	3.00	28.36	5.67	22.69	2900 g	2325
671	27.54	5.16	1.72	5.85	3.00	28.36	-	28.36	2900 g	--

TABLE III. (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	$LiO_{0.5}$	Melting Temp. °F.	Liquidus Temp. °F.
672	27.54	5.16	1.72	8.85	-	46.51	9.08	1.13	-	2900 g	2600
673	27.54	5.16	1.72	7.08	1.77	46.51	9.08	1.13	-	2900 g	--
674	27.54	5.16	1.72	5.31	3.54	46.51	9.08	1.13	-	2900 g	--
675	27.54	5.16	1.72	3.54	5.31	46.51	9.08	1.13	-	2900 g	2506
676	27.54	5.16	1.72	1.77	7.08	46.51	9.08	1.13	-	2900 g	--
677	27.54	5.16	1.72	-	8.85	46.51	9.08	1.13	-	2900 g	2515
678	27.54	5.16	1.72	7.08	-	46.51	9.08	1.13	1.77	2900 g	--
679	27.54	5.16	1.72	5.31	1.77	46.51	9.08	1.13	1.77	2900 g	--
680	27.54	5.16	1.72	3.54	3.54	46.51	9.08	1.13	1.77	2900 g	--
681	27.54	5.16	1.72	1.77	5.31	46.51	9.08	1.13	1.77	2900 g	--
682	27.54	5.16	1.72	-	7.08	46.51	9.08	1.13	1.77	2900 g	--
683	27.54	5.16	1.72	5.31	-	46.51	9.08	1.13	3.54	2900 g	2650
684	27.54	5.16	1.72	3.54	1.77	46.51	9.08	1.13	3.54	2900 g	--
685	27.54	5.16	1.72	1.77	3.54	46.51	9.08	1.13	3.54	2900 g	--
686	27.54	5.16	1.72	-	5.31	46.51	9.08	1.13	3.54	2900 g	2651
687	27.54	5.16	1.72	3.54	-	46.51	9.08	1.13	5.31	2900 g	--
688	27.54	5.16	1.72	1.77	1.77	46.51	9.08	1.13	5.31	2900 g	2651
689	27.54	5.16	1.72	-	3.54	46.51	9.08	1.13	5.31	2900 g	--
690	27.54	5.16	1.72	1.77	-	46.51	9.08	1.13	7.08	2900 g	--
691	27.54	5.16	1.72	-	1.77	46.51	9.08	1.13	7.08	2900 g	--
692	27.54	5.16	1.72	-	-	46.51	9.08	1.13	8.85	2900 g	2651

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	Ca0	Mg0	Ba0	$Na0_{0.5}$	$K0_{0.5}$	$Al0_{1.5}$	$Si0_2$	$B0_{1.5}$	$Li0_{0.5}$	Melting Temp. °F.	Liquidus Temp. °F.
693	36.00	12.00	12.00	-	-	24.00	8.00	8.00	-	2900 d	--
694	33.00	11.00	11.00	-	-	27.00	9.00	9.00	-	2900 g	--
695	30.00	10.00	10.00	-	-	30.00	10.00	10.00	-	2900 g	2505
696	27.00	9.00	9.00	-	-	33.00	11.00	11.00	-	2900 g	--
697	24.00	8.00	8.00	-	-	36.00	12.00	12.00	-	2900 g	--
698	36.00	12.00	12.00	2.00	2.00	21.00	7.00	7.00	1.00	2900 d	--
699	33.00	11.00	11.00	2.00	2.00	24.00	8.00	8.00	1.00	2900 d	--
700	30.00	10.00	10.00	2.00	2.00	27.00	9.00	9.00	1.00	2900 g	--
701	27.00	9.00	9.00	2.00	2.00	30.00	10.00	10.00	1.00	2900 g	--
702	24.00	8.00	8.00	2.00	2.00	33.00	11.00	11.00	1.00	2900 g	2350
703	33.00	11.00	11.00	4.00	4.00	21.00	7.00	7.00	2.00	2900 d	
704	30.00	10.00	10.00	4.00	4.00	24.00	8.00	8.00	2.00	2900 d	--
705	27.00	9.00	9.00	4.00	4.00	27.00	9.00	9.00	2.00	2900 g	--
706	24.00	8.00	8.00	4.00	4.00	30.00	10.00	10.00	2.00	2900 g	2510
707	21.00	7.00	7.00	-	-	39.00	13.00	13.00	-	2900 g	--
708	21.00	7.00	7.00	2.00	2.00	36.00	12.00	12.00	1.00	2900 g	--
709	21.00	7.00	7.00	4.00	4.00	33.00	11.00	11.00	2.00	2900 g	--
710	18.00	6.00	6.00	-	-	42.00	14.00	14.00	-	2900 g	--
711	18.00	6.00	6.00	2.00	2.00	39.00	13.00	13.00	1.00	2900 g	--
712	18.00	6.00	6.00	4.00	4.00	36.00	12.00	12.00	2.00	2900 g	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	$NaO_{0.5}$	$KO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	$LiO_{0.5}$	Melting Temp. °F.	Liquidus Temp. °F.
713	48.00	12.00	-	-	24.00	8.00	8.00	-	2900 d	--
714	44.00	11.00	-	-	27.00	9.00	9.00	-	2900 d	--
715	40.00	10.00	-	-	30.00	10.00	10.00	-	2900 g	2585
716	36.00	9.00	-	-	33.00	11.00	11.00	-	2900 g	--
717	32.00	8.00	-	-	36.00	12.00	12.00	-	2900 g	--
718	28.00	7.00	-	-	39.00	13.00	13.00	-	2900 g	2569
719	44.00	11.00	2.00	2.00	24.00	8.00	8.00	1.00	2900 d	--
720	40.00	10.00	2.00	2.00	27.00	9.00	9.00	1.00	2900 g*	--
721	36.00	9.00	2.00	2.00	30.00	10.00	10.00	1.00	2900 g	--
722	32.00	8.00	2.00	2.00	33.00	11.00	11.00	1.00	2900 g	2635
723	28.00	7.00	2.00	2.00	36.00	12.00	12.00	1.00	2900 g	--
724	24.00	6.00	2.00	2.00	39.00	13.00	13.00	1.00	2900 g	--
725	40.00	10.00	4.00	4.00	24.00	8.00	8.00	2.00	2900 d	--
726	36.00	9.00	4.00	4.00	27.00	9.00	9.00	2.00	2900 d	--
727	32.00	8.00	4.00	4.00	30.00	10.00	10.00	2.00	2900 g	2342
728	28.00	7.00	4.00	4.00	33.00	11.00	11.00	2.00	2900 g	--
729	24.00	6.00	4.00	4.00	36.00	12.00	12.00	2.00	2900 g	--
730	20.00	5.00	4.00	4.00	39.00	13.00	13.00	2.00	2900 g	2631
731	48.00	12.00	-	-	24.00	-	16.00	-	2900 d	--
732	44.00	11.00	-	-	27.00	-	18.00	-	2900 g	2400

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
733	40.00	10.00	-	-	-	30.00	-	20.00	2900 g	--
734	36.00	9.00	-	-	-	33.00	-	22.00	2900 g	--
735	32.00	8.00	-	-	-	36.00	-	24.00	2900 g	---
736	28.00	7.00	-	-	-	39.00	-	26.00	2900 g	--
737	24.00	6.00	-	-	-	42.00	-	28.00	2900 g	2651
738	44.00	11.00	2.00	2.00	1.00	24.00	-	16.00	2900 d	--
739	40.00	10.00	2.00	2.00	1.00	27.00	-	18.00	2900 g	--
740	36.00	9.00	2.00	2.00	1.00	30.00	-	20.00	2900 g	2456
741	32.00	8.00	2.00	2.00	1.00	33.00	-	22.00	2900 g	--
742	28.00	7.00	2.00	2.00	1.00	36.00	-	24.00	2900 g	--
743	24.00	6.00	2.00	2.00	1.00	39.00	-	26.00	2900 g	--
744	20.00	5.00	2.00	2.00	1.00	42.00	-	28.00	2900 g	--
745	40.00	10.00	4.00	4.00	2.00	24.00	-	16.00	2900 d	--
746	36.00	9.00	4.00	4.00	2.00	27.00	-	18.00	2900 g	--
747	32.00	8.00	4.00	4.00	2.00	30.00	-	20.00	2900 g	2415
748	28.00	7.00	4.00	4.00	2.00	33.00	-	22.00	2900 g	--
749	24.00	6.00	4.00	4.00	2.00	36.00	-	24.00	2900 g	above 2600
750	20.00	5.00	4.00	4.00	2.00	39.00	-	26.00	2900 g	--
751	16.00	4.00	4.00	4.00	2.00	42.00	-	28.00	2900 g	--
752	48.00	12.00	-	-	-	24.00	16.00	-	2900 d	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	Melting Temp. °F.	Liquidus Temp. °F.
753	44.00	11.00	-	-	-	27.00	18.00	2900 d	--
754	40.00	10.00	-	-	-	30.00	20.00	2900 g	--
755	36.00	9.00	-	-	-	33.00	22.00	2900 g	--
756	32.00	8.00	-	-	-	36.00	24.00	2900 g	--
757	28.00	7.00	-	-	-	39.00	26.00	2900 g	--
758	24.00	6.00	-	-	-	42.00	28.00	2900 g	--
759	44.00	11.00	2.00	2.00	1.00	24.00	16.00	2900 d	--
760	40.00	10.00	2.00	2.00	1.00	27.00	18.00	2900 d	--
761	36.00	9.00	2.00	2.00	1.00	30.00	20.00	2900 g	--
762	32.00	8.00	2.00	2.00	1.00	33.00	22.00	2900 g	--
763	28.00	7.00	2.00	2.00	1.00	36.00	24.00	2900 g	2625
764	24.00	6.00	2.00	2.00	1.00	39.00	26.00	2900 g	--
765	20.00	5.00	2.00	2.00	1.00	42.00	28.00	2900 g	--
766	40.00	10.00	4.00	4.00	2.00	24.00	16.00	2900 d	--
767	36.00	9.00	4.00	4.00	2.00	27.00	18.00	2900 g	--
768	32.00	8.00	4.00	4.00	2.00	30.00	20.00	2900 g	--
769	28.00	7.00	4.00	4.00	2.00	33.00	22.00	2900 g	2580
770	24.00	6.00	4.00	4.00	2.00	36.00	24.00	2900 g	--
771	20.00	5.00	4.00	4.00	2.00	39.00	26.00	2900 g	--
772	16.00	4.00	4.00	4.00	2.00	42.00	28.00	2900 g	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINUM GLASSES

Composition No.	CaO	MgO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
773	44.00	11.00	1.00	2.00	2.00	24.00	8.00	8.00	2900 d	--
774	40.00	10.00	1.00	2.00	2.00	27.00	9.00	9.00	2900 d	--
775	36.00	9.00	1.00	2.00	2.00	30.00	10.00	10.00	2900 g	2475
776	32.00	8.00	1.00	2.00	2.00	33.00	11.00	11.00	2900 g	--
777	28.00	7.00	1.00	2.00	2.00	36.00	12.00	12.00	2900 g	--
778	24.00	6.00	1.00	2.00	2.00	39.00	13.00	13.00	2900 g	--
779	20.00	5.00	1.00	2.00	2.00	42.00	14.00	14.00	2900 g	--
780	40.00	10.00	2.00	4.00	4.00	24.00	8.00	8.00	2900 d	--
781	36.00	9.00	2.00	4.00	4.00	27.00	9.00	9.00	2900 d	--
782	32.00	8.00	2.00	4.00	4.00	30.00	10.00	10.00	2900 g	--
783	28.00	7.00	2.00	4.00	4.00	33.00	11.00	11.00	2900 g	2538
784	24.00	6.00	2.00	4.00	4.00	36.00	12.00	12.00	2900 g	--
785	20.00	5.00	2.00	4.00	4.00	39.00	13.00	13.00	2900 g	--
786	16.00	4.00	2.00	4.00	4.00	42.00	14.00	14.00	2900 g	--
787	36.00	9.00	3.00	6.00	6.00	24.00	8.00	8.00	2900 d	--
788	32.00	8.00	3.00	6.00	6.00	27.00	9.00	9.00	2900 d	--
789	28.00	7.00	3.00	6.00	6.00	30.00	10.00	10.00	2900 g	2200
790	24.00	6.00	3.00	6.00	6.00	33.00	11.00	11.00	2900 g	--
791	20.00	5.00	3.00	6.00	6.00	36.00	12.00	12.00	2900 g	---
792	16.00	4.00	3.00	6.00	6.00	39.00	13.00	13.00	2900 g	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	Melting Temp. °F.	Liquidus Temp, °F.
793	44.00	11.00	2.00	1.00	2.00	24.00	8.00	8.00	2900 d	--
794	40.00	10.00	2.00	1.00	2.00	27.00	9.00	9.00	2900 g	2376
795	36.00	9.00	2.00	1.00	2.00	30.00	10.00	10.00	2900 g	--
796	32.00	8.00	2.00	1.00	2.00	33.00	11.00	11.00	2900 g	2525
797	28.00	7.00	2.00	1.00	2.00	36.00	12.00	12.00	2900 g	--
798	24.00	6.00	2.00	1.00	2.00	39.00	13.00	13.00	2900 g	--
799	20.00	5.00	2.00	1.00	2.00	42.00	14.00	14.00	2900 g	--
800	40.00	10.00	4.00	2.00	4.00	24.00	8.00	8.00	2900 d	--
801	36.00	9.00	4.00	2.00	4.00	27.00	9.00	9.00	2900 g	--
802	32.00	8.00	4.00	2.00	4.00	30.00	10.00	10.00	2900 g	2600
803	28.00	7.00	4.00	2.00	4.00	33.00	11.00	11.00	2900 g	--
804	24.00	6.00	4.00	2.00	4.00	36.00	12.00	12.00	2900 g	--
805	20.00	5.00	4.00	2.00	4.00	39.00	13.00	13.00	2900 g	--
806	16.00	4.00	4.00	2.00	4.00	42.00	14.00	14.00	2900 g	--
807	36.00	9.00	6.00	3.00	6.00	24.00	8.00	8.00	2900 d	--
808	32.00	8.00	6.00	3.00	6.00	27.00	9.00	9.00	2900 d	--
809	28.00	7.00	6.00	3.00	6.00	30.00	10.00	10.00	2900 g	2500
810	24.00	6.00	6.00	3.00	6.00	33.00	11.00	11.00	2900 g	--
811	20.00	5.00	6.00	3.00	6.00	36.00	12.00	12.00	2900 g	--
812	16.00	4.00	6.00	3.00	6.00	39.00	13.00	13.00	2900 g	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	BaO	Melting Temp. °F.	Liquidus Temp. °F.
813	48.00	-	-	-	-	24.00	8.00	8.00	12.00	2900 d	--
814	44.00	-	-	-	-	27.00	9.00	9.00	11.00	2900 g	--
815	40.00	-	-	-	-	30.00	10.00	10.00	10.00	2900 g	--
816	36.00	-	-	-	-	33.00	11.00	11.00	9.00	2900 g	--
817	32.00	-	-	-	-	36.00	12.00	12.00	8.00	2900 g	--
818	28.00	-	-	-	-	39.00	13.00	13.00	7.00	2900 g	--
819	24.00	-	-	-	-	42.00	14.00	14.00	6.00	2900 g	--
820	44.00	-	2.00	2.00	1.00	24.00	8.00	8.00	11.00	2900 d	--
821	40.00	-	2.00	2.00	1.00	27.00	9.00	9.00	10.00	2900 d	--
822	36.00	-	2.00	2.00	1.00	30.00	10.00	10.00	9.00	2900 g	--
823	32.00	-	2.00	2.00	1.00	33.00	11.00	11.00	8.00	2900 g	--
824	28.00	-	2.00	2.00	1.00	36.00	12.00	12.00	7.00	2900 g	
825	24.00	-	2.00	2.00	1.00	39.00	13.00	13.00	6.00	2900 g	--
826	20.00	-	2.00	2.00	1.00	42.00	14.00	14.00	5.00	2900 g	--
827	40.00	-	4.00	4.00	2.00	24.00	8.00	8.00	10.00	2900 d	--
828	36.00	-	4.00	4.00	2.00	27.00	9.00	9.00	9.00	2900 d	--
829	32.00	-	4.00	4.00	2.00	30.00	10.00	10.00	8.00	2900 g	--
830	28.00	-	4.00	4.00	2.00	33.00	11.00	11.00	7.00	2900 g	--
831	24.00	-	4.00	4.00	2.00	36.00	12.00	12.00	6.00	2900 g	--
832	20.00	-	4.00	4.00	2.00	39.00	13.00	13.00	5.00	2900 g	--
833	16.00	-	4.00	4.00	2.00	42.00	14.00	14.00	4.00	2900 g	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	$FeO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
852	30.00	5.00	-	6.00	3.00	6.00	30.00	10.00	10.00	-	2900 g	2345
853	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	10.00	-	2900 g	2315
854	28.00	7.00	-	3.00	3.00	9.00	30.00	10.00	10.00	-	2900 g	2630
855	28.00	7.00	-	9.00	3.00	3.00	30.00	10.00	10.00	-	2900 g	2655
856	28.00	7.00	-	6.00	-	9.00	30.00	10.00	10.00	-	2900 g	2600
857	28.00	7.00	-	-	6.00	9.00	30.00	10.00	10.00	-	2900 g	2600
858	28.00	7.00	-	6.00	3.00	6.00	33.00	7.00	10.00	-	2900 g	2600
859	28.00	7.00	-	6.00	3.00	6.00	30.00	7.00	13.00	-	2900 g	2450
860	28.00	7.00	-	6.00	3.00	6.00	33.50	-	16.50	-	2900 g	2390
861	28.00	7.00	-	6.00	3.00	6.00	40.00	-	10.00	-	2900 g	--
862	27.54	5.16	1.72	5.85	3.00	-	51.05	-	-	5.67	2900 d	--
863	27.54	5.16	1.72	5.85	3.00	-	45.38	-	-	11.34	2900 d	--
864	27.54	5.16	1.72	5.85	3.00	-	39.70	-	-	17.02	2900 d	--
865	27.54	5.16	1.72	5.85	3.00	-	45.38	-	5.67	5.67	2900 d	--
866	27.54	5.16	1.72	5.85	3.00	-	39.70	-	5.67	11.34	2900 d	--
867	27.54	5.16	1.72	5.85	3.00	-	34.03	-	5.67	17.02	2900 d	--
868	27.54	5.16	1.72	5.85	3.00	-	39.70	-	11.34	5.67	2900 d	--
869	27.54	5.16	1.72	5.85	3.00	-	34.03	-	11.34	11.34	2900 d	--
870	27.54	5.16	1.72	5.85	3.00	-	34.03	-	17.02	5.67	2900 d	--
871	27.54	5.16	1.72	5.85	3.00	-	28.36	-	17.02	11.34	2900 d	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	$FeO_{1.5}$	Melting Temp. °F.	Liquidus Temp. °F.
872	24.00	6.00	6.00	3.00	6.00	30.00	10.00	10.00	5.00	2900 d	--
873	20.00	5.00	6.00	3.00	6.00	30.00	10.00	10.00	10.00	2900 d	--
874	16.00	4.00	6.00	3.00	6.00	30.00	10.00	10.00	15.00	2900 d	--
875	12.00	3.00	6.00	3.00	6.00	30.00	10.00	10.00	20.00	2900 d	--
876	24.00	6.00	6.00	3.00	6.00	35.00	7.50	7.50	5.00	2900 d	--
877	20.00	5.00	6.00	3.00	6.00	35.00	7.50	7.50	10.00	2900 d	--
878	16.00	4.00	6.00	3.00	6.00	35.00	7.50	7.50	15.00	2900 d	--
879	12.00	3.00	6.00	3.00	6.00	35.00	7.50	7.50	20.00	2900 d	--
880	24.00	6.00	6.00	3.00	6.00	40.00	5.00	5.00	5.00	2900 d	--
881	20.00	5.00	6.00	3.00	6.00	40.00	5.00	5.00	10.00	2900 d	--
882	16.00	4.00	6.00	3.00	6.00	40.00	5.00	5.00	15.00	2900 d	--
883	12.00	3.00	6.00	3.00	6.00	40.00	5.00	5.00	20.00	2900 d	--
884	24.00	6.00	6.00	3.00	6.00	45.00	2.50	2.50	5.00	2900 d	--
885	20.00	5.00	6.00	3.00	6.00	45.00	2.50	2.50	10.00	2900 d	--
886	16.00	4.00	6.00	3.00	6.00	45.00	2.50	2.50	15.00	2900 d	--
887	12.00	3.00	6.00	3.00	6.00	45.00	2.50	2.50	20.00	2900 d	--
888	24.00	6.00	6.00	3.00	6.00	50.00	-	-	5.00	2900 d	--
889	20.00	5.00	6.00	3.00	6.00	50.00	-	-	10.00	2900 d	--
890	16.00	4.00	6.00	3.00	6.00	50.00	-	-	15.00	2900 d	--
891	12.00	3.00	6.00	3.00	6.00	50.00	-	-	20.00	2900 d	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	TiO_2	ZrO_2	Melting Temp. °F.	Liquidus Temp. °F.
892	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	8.00	8.00	-	2900 d	--
893	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	6.00	4.00	-	2900 d	--
894	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	4.00	6.00	-	2900 s	--
895	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	2.00	8.00	-	2900 s	--
896	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	-	10.00	-	2900 s	
897	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	8.00	-	2.00	2900 d	--
898	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	6.00	2.00	2.00	2900 d	2560
899	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	4.00	4.00	2.00	2900 d	--
900	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	2.00	6.00	2.00	2900 d	--
901	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	-	8.00	4.00	2900 d	--
902	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	6.00	-	4.00	2900 d	--
903	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	4.00	2.00	4.00	2900 d	--
904	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	2.00	4.00	4.00	2900 d	--
905	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	-	6.00	4.00	2900 d	--
906	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	4.00	-	6.00	2900 s	--
907	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	2.00	2.00	6.00	2900 s	--
908	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	-	4.00	6.00	2900 s	--
909	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	2.00	-	8.00	2900 s	--
910	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	-	2.00	8.00	2900 s	--
911	28.00	5.00	2.00	6.00	3.00	6.00	30.00	10.00	-	-	10.00	2900 s	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	TiO_2	ZrO_2	Melting Temp. °F.	Liquidus Temp. °F.
912	28.00	5.00	2.00	6.00	3.00	6.00	30.00	8.00	10.00	2.00	-	2900 d	--
913	28.00	5.00	2.00	6.00	3.00	6.00	30.00	6.00	10.00	4.00	-	2900 d	--
914	28.00	5.00	2.00	6.00	3.00	6.00	30.00	4.00	10.00	6.00	-	2900 d	--
915	28.00	5.00	2.00	6.00	3.00	6.00	30.00	2.00	10.00	8.00	-	2900 d	--
916	28.00	5.00	2.00	6.00	3.00	6.00	30.00	-	10.00	10.00	-	2900 d	--
917	28.00	5.00	2.00	6.00	3.00	6.00	30.00	6.00	10.00	2.00	2.00	2900 d	2530
918	28.00	5.00	2.00	6.00	3.00	6.00	30.00	4.00	10.00	4.00	2.00	2900 d	--
919	28.00	5.00	2.00	6.00	3.00	6.00	30.00	6.00	10.00	-	4.00	2900 s	--
920	28.00	5.00	2.00	6.00	3.00	6.00	30.00	4.00	10.00	2.00	4.00	2900 s	--
921	28.00	5.00	2.00	6.00	3.00	6.00	30.00	2.00	10.00	2.00	6.00	2900 s	--
922	28.00	5.00	2.00	6.00	3.00	6.00	30.00	9.00	9.00	2.00	-	2900 d	2375
923	28.00	5.00	2.00	6.00	3.00	6.00	30.00	8.00	8.00	2.00	2.00	2900 d	2530
924	28.00	5.00	2.00	6.00	3.00	6.00	30.00	7.00	7.00	4.00	2.00	2900 d	--
925	28.00	5.00	2.00	6.00	3.00	6.00	30.00	6.00	6.00	4.00	4.00	2900 d	--
926	28.00	5.00	2.00	6.00	3.00	6.00	28.00	10.00	10.00	2.00	-	2900 d	--
927	28.00	5.00	2.00	6.00	3.00	6.00	26.00	10.00	10.00	4.00	-	2900 d	2480
928	28.00	5.00	2.00	6.00	3.00	6.00	24.00	10.00	10.00	6.00	-	2900 d	--
929	28.00	5.00	2.00	6.00	3.00	6.00	22.00	10.00	10.00	8.00	-	2900 d	--
930	28.00	5.00	2.00	6.00	3.00	6.00	20.00	10.00	10.00	10.00	-	2900 d	--
931	28.00	5.00	2.00	6.00	3.00	6.00	26.00	10.00	10.00	2.00	2.00	2900 d	--

TABLE III (Cont.)

SYSTEMATIC STUDY OF CALCIUM ALUMINATE GLASSES

Composition No.	CaO	MgO	BaO	$NaO_{0.5}$	$KO_{0.5}$	$LiO_{0.5}$	$AlO_{1.5}$	SiO_2	$BO_{1.5}$	TiO_2	ZrO_2	Melting Temp. °F.	Liquidus Temp. °F.
932	28.00	5.00	2.00	6.00	3.00	6.00	24.00	10.00	10.00	4.00	2.00	2900 d	----
933	28.00	5.00	2.00	6.00	3.00	6.00	24.00	10.00	10.00	2.00	4.00	2900 s	----
934	28.00	5.00	2.00	6.00	3.00	6.00	22.00	10.00	10.00	2.00	6.00	2900 s	----
935	28.00	5.00	2.00	6.00	3.00	6.00	28.00	9.00	9.00	2.00	2.00	2900 d	2510
936	28.00	5.00	2.00	6.00	3.00	6.00	28.00	8.00	8.00	4.00	2.00	2900 d	above 2600
937	28.00	5.00	2.00	6.00	3.00	6.00	26.00	8.00	8.00	4.00	4.00	2900 s	----
938	28.00	5.00	2.00	6.00	3.00	6.00	26.00	8.00	8.00	2.00	6.00	2900 s	----
939	28.00	5.00	2.00	6.00	3.00	6.00	26.00	8.00	8.00	6.00	2.00	2900 d	----
940	30.00	3.00	2.00	6.00	3.00	6.00	30.00	10.00	6.00	2.00	2.00	2900 d	2550
941	30.00	3.00	2.00	9.00	3.00	3.00	30.00	10.00	6.00	2.00	2.00	2900 d	2565
942	30.00	3.00	2.00	6.00	6.00	3.00	30.00	10.00	6.00	2.00	2.00	2900 d	2565
943	28.00	4.00	3.00	6.00	6.00	3.00	30.00	10.00	6.00	2.00	2.00	2900 d	2550
944	28.00	3.00	2.00	6.00	6.00	3.00	32.00	10.00	6.00	2.00	2.00	2900 d	2535
945	28.00	3.00	2.00	5.00	3.00	3.00	32.00	10.00	8.00	2.00	2.00	2900 d	2485
946	28.00	3.00	2.00	9.00	5.00	3.00	30.00	10.00	6.00	2.00	2.00	2900 d	2560
947	28.00	3.00	2.00	11.00	3.00	3.00	30.00	10.00	6.00	2.00	2.00	2900 d	2600
948	28.00	3.00	2.00	6.00	6.00	3.00	30.00	10.00	8.00	2.00	2.00	2900 d	2600
949	32.00	3.00	2.00	6.00	6.00	3.00	30.00	10.00	4.00	2.00	2.00	2900 d	2590

TABLE IV.

PHYSICAL PROPERTIES OF CALCIUM ALUMINATE GLASSES

Glass No.	log. viscosity in poises 0.5 °F.	0.75 °F.	1.00 °F.	1.25 °F.	1.50 °F.	1.75 °F.	Specific Gravity gm/ml	$Ex10^{-6}$ psi	Specific Modulus psi/lb/cu.ft. $x10^{-4}$
Std. Textile	--	--	--	--	2650	2590	2.59	11.95	7.39
632	--	--	--	2610	2515	2430	2.90	15.0	8.29
633	--	--	--	2700	devitrification	--	3.00	16.3	8.39
638	--	--	--	2615	2530	2460	2.83	15.45	8.74
639	--	--	--	2655	2565	--	3.09	15.10	7.83
653	--	--	--	2630	2535	2430	2.90	15.25	8.43
656	--	--	2750	2635	2530	--	2.88	14.28	7.94
657	--	2755	2640	2535	2455	2380	2.90	15.52	8.57
659	--	2720	2595	2485	--	--	2.91	15.41	8.48
661	--	2740	2615	2505	2415	--	2.88	--	--
662	--	2575	2460	2360	--	--	2.89	14.63	8.11
664	--	--	--	--	--	--	2.89	--	--
666	2650	2475	2330	2220	2140	2075	2.87	14.60	8.15
670	2430	2305	2195	2100	2020	1940	2.85	13.44	7.55
672	--	--	2650	2555	2480	2410	2.91	15.68	8.63
675	--	--	2685	2610	2535	--	2.89	15.16	8.40
677	--	--	--	2665	2565	2485	2.88	14.75	8.19
683	--	--	2610	2495	--	--	2.92	15.85	8.69
686	--	--	2640	2510	2400	2300	2.90	15.42	8.52
688	--	--	--	--	--	--	2.91	15.90	8.75

TABLE IV. (Cont.)

PHYSICAL PROPERTIES OF CALCIUM ALUMINATE GLASSES

Glass No.	log. viscosity in poises 0.5 °F.	0.75 °F.	1.00 °F.	1.25 °F.	1.50 °F.	1.75 °F.	Specific Gravity gm/ml	$Ex10^{-6}$ psi	Specific Modulus psi/lb/cu.ft. $x10^{-4}$
692	--	2615	2510	2415	--	--	2.92	16.20	8.89
695	2595	--	--	--	--	--	3.28	14.27	6.97
702	2750	2595	2470	2385	2315	--	3.16	14.78	7.49
706	2735	2570	2450	--	--	--	3.14	12.60	6.43
715	--	2615	2495	2390	2300	--	2.92	15.69	8.61
718	2715	2605	2495	2385	--	--	2.83	14.65	8.29
722	2695	2550	2430	2350	--	--	2.84	14.79	8.34
727	2690	2555	2430	2355	--	--	2.84	15.19	8.56
730	--	2705	2590	2495	2410	2345	2.72	14.06	8.28
732	2475	2390	--	--	--	--	2.91	--	--
737	--	--	--	2700	2620	2550	--	--	--
740	2345	2215	2100	--	--	--	2.86	--	--
763	--	--	2605	--	--	--	2.83	15.04	8.51
769	--	--	2630	2510	2410	--	2.81	14.81	8.44
775	--	--	2390	2290	2220	2165	2.87	15.3	8.54
783	2475	2350	--	--	--	--	2.80	14.8	8.46
789	2600	2430	2310	2215	2130	2050	2.79	15.0	8.61
794	2474	2350	--	--	--	--	2.90	15.37	8.49
796	--	2445	2355	--	--	--	2.85	15.20	8.54
802	2620	2475	--	--	--	--	2.87	15.28	8.53

TABLE IV. (Cont.)

PHYSICAL PROPERTIES OF CALCIUM ALUMINATE GLASSES

Glass No.	log. viscosity in poises 0.5 °F.	0.75 °F.	1.00 °F.	1.25 °F.	1.50 °F.	1.75 °F.	Specific Gravity gm/ml	$Ex10^{-6}$ psi	Specific Modulus psi/lb/cu.ft. $x 10^{-4}$
809	2570	2430	2305	2195	2100	2020	2.80	15.15	8.67
852	2570	2430	2305	2195	2100	2020	2.81	15.10	8.61
853	2595	2430	2305	2205	2115	2035	2.89	15.20	8.43
854	2530	2370	2250	2150	2075	2000	2.81	15.36	8.76
855	2600	2445	2320	2215	2125	2050	2.81	15.0	8.55
856	--	2524	2260	2125	2025	1940	2.80	13.8	7.89
857	2560	2435	2315	2210	2120	2040	2.79	--	--
858	2580	2445	2315	2200	2100	2005	2.80	--	--
859	--	2360	2215	2120	2035	1970	2.79	--	--
860	2505	2345	2225	2125	2025	--	2.79	13.94	8.00
898	2555	2420	2310	2230	2155	2090	2.97	15.30	8.25
940	2575	2430	2325	2245	2175	2115	2.93	14.74	8.06
941	--	2470	2335	2245	2175	2120	2.98	16.23	8.73
942	2520	2435	2365	2300	--	--	2.98	16.24	8.73
945	--	2490	2375	2285	2205	2130	2.97	15.00	8.09
946	2585	2450	2350	2290	2200	2130	2.965	14.81	7.99
947	2580	2455	2365	2285	--	--	2.977	14.97	8.05
949	--	2480	2375	--	--	--	3.00	15.25	8.14

The results of this compositional study with regards to the elastic modulus of the annealed calcium aluminate type glass and the viscosity of the melt as a function of the composition were as follows:

1. The substitution of silicon or boron for aluminum decreases Young's modulus.

2. The substitution of barium for calcium decreases Young's modulus.

3. The substitution of magnesium for calcium increases Young's modulus.

4. The substitution of potassium for sodium decreases Young's modulus.

5. The substitution of lithium for sodium increases Young's modulus.

6. The substitution of alkali ions or aluminum, silicon and boron for alkaline earth ion decreases Young's modulus.

7. The substitution of barium or magnesium for calcium increases the viscosity of the melt.

8. The substitution of potassium for sodium increases the viscosity of the melt.

9. The substitution of lithium for sodium decreases the viscosity of the melt.

10. The substitution of silicon for aluminum increases the viscosity of the melt only slightly.

11. The substitution of boron for aluminum greatly decreases the viscosity of the melt.

No general rule could be formulated with regards to liquidus temperatures. No satisfactory glasses were found which contained more than two or three cation percent of titania, zirconia, iron, manganese, or copper oxides. Figure 2 represents the Young's modulus data listed in TableIII. The glasses have been grouped together to show the effects of the substitution of one ion for another.

Compositions Nos. 632, 633, 638 and 639 differ only in relative amounts of Ca ions, Ba ions and Mg ions in the total alkaline earth present in the glass. All other components have been kept at a constant ion percent.

No. 632 contains all of the alkaline earth ions as Ca ions.

In No. 633, 20% of the Ca ions have been replaced by Ba ions.

In No. 638, 20% of the Ca ions have been replaced by Mg ions.

In No. 639, 20% of the Ca ions have been replaced by Ba ions and 20% by Mg ions.

Compositions Nos. 715, 695, 722, 727 and 706 are examples of the replacement of Ca ions by Ba ions. These glasses are not comparable to any other glass except the one to which they are paired on the chart, because all others contain variations in other components as well as Ca ions and Ba ions. In each pair, the second glass was identical to the first except for the replacement of 20% of the Ca ions by Ba ions.

Evaluation of this information on the replacement of Ca ions by Ba ions and Mg ions, as it affects Young's modulus, leads to these conclusions:

1. The replacement of Ca ions by Ba ions usually decreases Young's modulus.

2. The replacement of Ca ions by Mg ions increases Young's modulus.

In Figure 2, Compositions Nos. 692, 683, 686 and 688 differ only in the relative amounts of Li ions, Na ions and K ions in the total alkali ions present. All other components were kept at a constant ion percent.

Composition No. 692 contains all of the alkali ions as Li ions.

In No. 683, 60% of the Li ions have been replaced by Na ions.

In No. 686, 60% of the Li ions have been replaced by K ions.

In No. 688, 20% of the Li ions have been replaced by Na ions and 20% by K ions.

Evaluation of this data on the effect of the relative amounts of each of the alkali ions present on Young's modulus leads to the following conclusions:

1. The replacement of Li ions by Na ions decreases Young's modulus.

2. The replacement of Li ions by K ions decreases Young's modulus.

3. The replacement of Na ions by K ions decreases Young's modulus.

In Figure 2, Compositions Nos. 395, 653, 657 and 659 differ only in the relative amounts of Al ions, Si ions and B ions present in the composition. All other components remain constant.

Composition 395 contains only Al ions.

In No. 653, 20% of the Al ions are replaced by Si ions.

In No. 656, 50% of the Al ions are replaced by Si ions.

In No. 657, 10% of the Al ions are replaced by B ions.

In No. 659, 30% of the Al ions are replaced by Si ions and 10% by B ions.

The conclusion from this data is:

1. The replacement of Al ions by either Si ions or B ions decreases Young's modulus.

The effect of the substitution of alkaline earth ions for alkali ions can be seen by comparing No. 715 and No. 727 in Figure 2. No. 715 is different from No. 727 only in the replacement of 10% of the total alkaline earth ions by alkali ions on an ion for ion basis. No. 715 contains no alkali ions. This same observation can be seen in the comparison of No. 695 and No. 706. No. 706 contains 10% alkali ions which have been substituted for alkaline earth ions.

The effect of the substitution of alkaline earth ions for Al, Si and B ions can be seen by comparing No. 715 and No. 718. No. 718 is not in Figure 2 but is listed in Table III. No. 715 was identical to No. 718 except for the replacement of 15% of the Al, Si and B ions of No. 718 by alkaline earth ions. The alkali ions and the relative quantities of Al ions, Si ions and B ions were held constant.

The above comparisons lead to the conclusion that:

1. The substitution of alkali ions for alkaline earth ions decreases Young's modulus.

2. The substitution of Al, Si and B ions for alkaline earth ions decreases Young's modulus.

The effect of the substitution of alkali ions for Al, Si and B ions can be seen by comparing No. 706 and No. 702. No. 706 was identical to No. 702 except for the replacement of 5% of the Al, Si and B ions of No. 702 by alkali ions.

This observation leads to the conclusion that the replacement of Al, Si and B ions by alkali ions decreases Young's modulus of the resultant glass.

Figure 3 lists the same glasses as Figure 2 but with respect to the liquidus temperatures of the glasses instead of Young's moduli.

As would be expected, no general rules can be formulated regarding the effect of ion for ion replacement on the liquidus temperatures.

Figure 4 also contains most of the glasses shown on Figure 2. Viscosity measurements could not be made on a few of the glasses or the viscosities were much too low to be considered here.

From Figure 4 a few conclusions can be made. These are:

1. The substitution of Ba ions for Ca ions increases the viscosity of the melt.

2. The substitution of Mg ions for Ca ions increases the viscosity.

3. The substitution of Na ions for Li ions increases the viscosity.

4. The substitution of K ions for Na ions increases the viscosity.

5. The substitution of Si ions for Al ions increases the viscosity.

6. The substitution of B ions for Al ions decreases the viscosity.

It was observed that the area of glass formation was limited to compositions containing at least 50 cation percent of the acidic oxides, namely, alumina, silica, boron oxide, titania or zirconia. This area is shown in Figure 1, page 68. Glasses were formed in this series with as little as 20 cation percent and as much as 45 cation percent total alkaline earth oxides. The major portion of this alkaline earth oxide being in the form of calcium oxide. Substitution of magnesium oxide or barium oxide for calcium oxide produced glasses until about 20% of the total alkaline earth oxide was substituted. The alkali metal oxide content of these glasses was kept below 10 cation percent because of the tendency of these oxides to lower the modulus of the glass. Complete substitution of lithium oxide or potassium oxide for sodium oxide was found to be possible.

The color of these glasses was found to be dependent on the composition and to the melting history of the glass. Glass compositions near the limit of glass formation, that is, nearly 50 cation percent acidic components, gave blue or light green colored glasses, whereas glasses containing more than 50 cation percent acidic components gave light amber to colorless glasses. The light amber to colorless glasses which were originally melted in a gas fired furnace 2900°F. turned dark brown while in an electric muffle furnace for viscosity measurements. This color change from light amber to dark brown was found to be reversible. Remelting of the glass in the gas fired furnace restored the light color. The colors observed in these glasses was thought to be dissolved platinum from the platinum crucibles. However, the weight loss of the crucibles used for melting these glasses was found to be less than for platinum crucibles used for melting standard silicate glasses. No reasonable explanation for the color changes has been found.

The surface tension of these glasses was determined for only the two representative samples, No. 390 and No. 507. No. 507 was found to have a surface tension between 370 and 360 dyne-centimeters over the temperature range 2400°F. to 2800°F., while over this same temperature range, No. 390 had a surface tension from 398 to 388 dyne-centimeters. This can be compared to a surface tension of approximately 325 dyne-centimeters for standard textile glass. The surface tension was measured by the maximum bubble pressure method described in Appendix IV.

The dielectric properties of three of these glasses was determined at 9,455 megacycles by E. R. Schatz at Carnegie Institute of Technology.

No. 508 had a dielectric constant of 9.17 and a loss tangent of 0.006; No. 508-B, dielectric constant 8.94, loss tangent 0.005; No. 395, dielectric constant, 9.28, loss tangent 0.009. Our standard textile glass has a dielectric constant of 6.33 and a loss tangent of 0.006.

The addition of BeO as the oxide to the calcium aluminate compositions was not attempted because of the toxicity of this oxide. The addition of BeO from beryl, $2\ BeO \cdot Al_2O_3 \cdot 6\ SiO_2$, was made in Compositions Nos. 505B, 506 B, 507 B, 508 B and 509 B. BeO was substituted for CaO in these compositions to the extent that all of the SiO_2 in the composition was from the beryl. These compositions had higher elastic moduli than the corresponding glasses Nos. 505, 507 and 509 but they had higher liquidus temperatures and tended to devitrify on cooling.

An exploratory search for high modulus glasses was made in the stannic oxide system. Approximately 190 compositions were investigated which contained from twenty-five to seventy cation percent stannic oxide. The remaining cation of these compositions contained varying amounts of the alkali oxides, the alkaline earth oxides, aluminum oxide and silica. Small quantities of glass were made in this system, but not in sufficient quantity for physical property measurements. Devitrification of the melts and high melting temperatures were the major obstacles. Clay crucibles were used for all the exploratory melts in this field because of attack on platinum by the tin. In several cases, the glass which was formed in the melt was due to increased silica and alumina in the composition from the melting crucible.

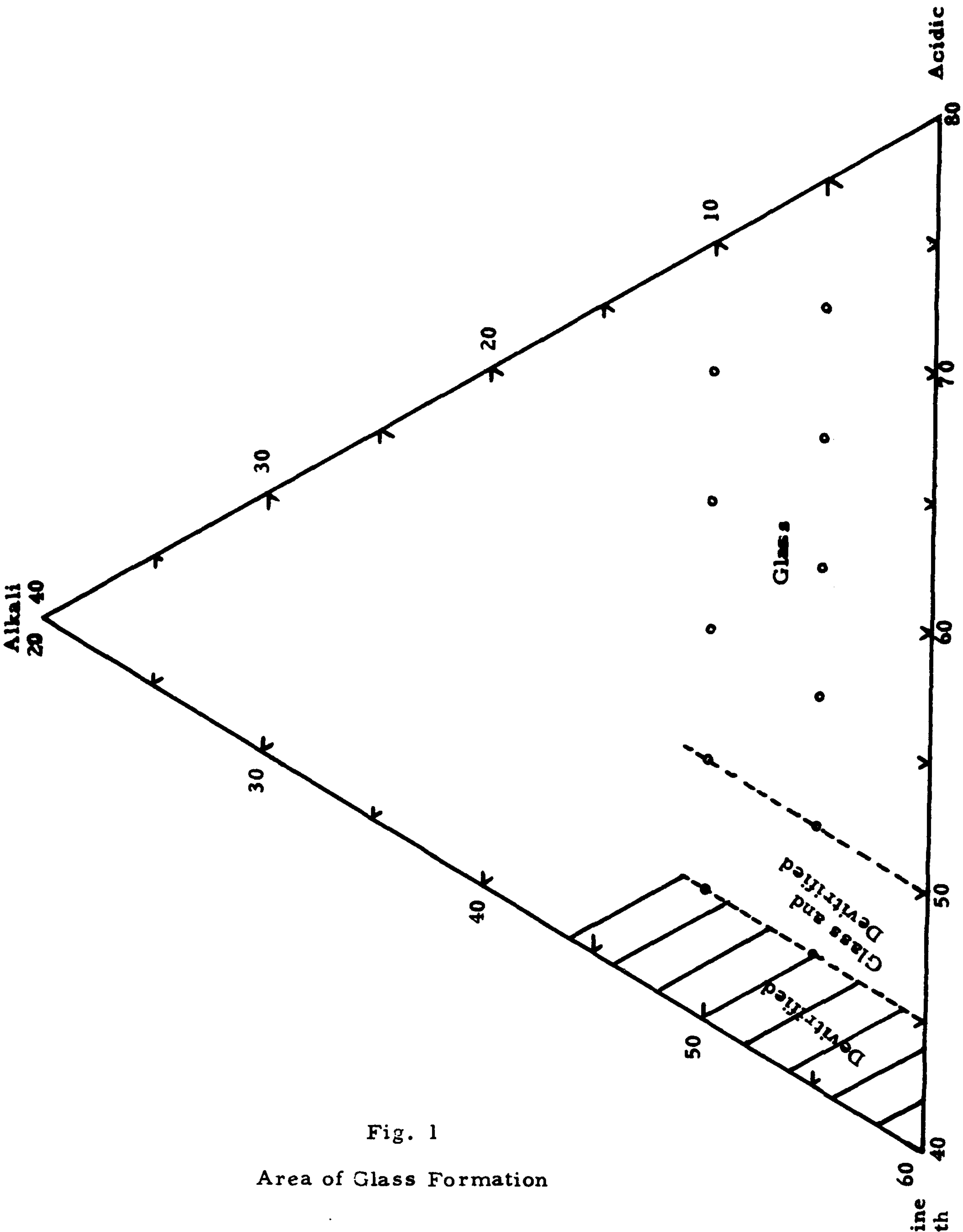

Fig. 1

Area of Glass Formation

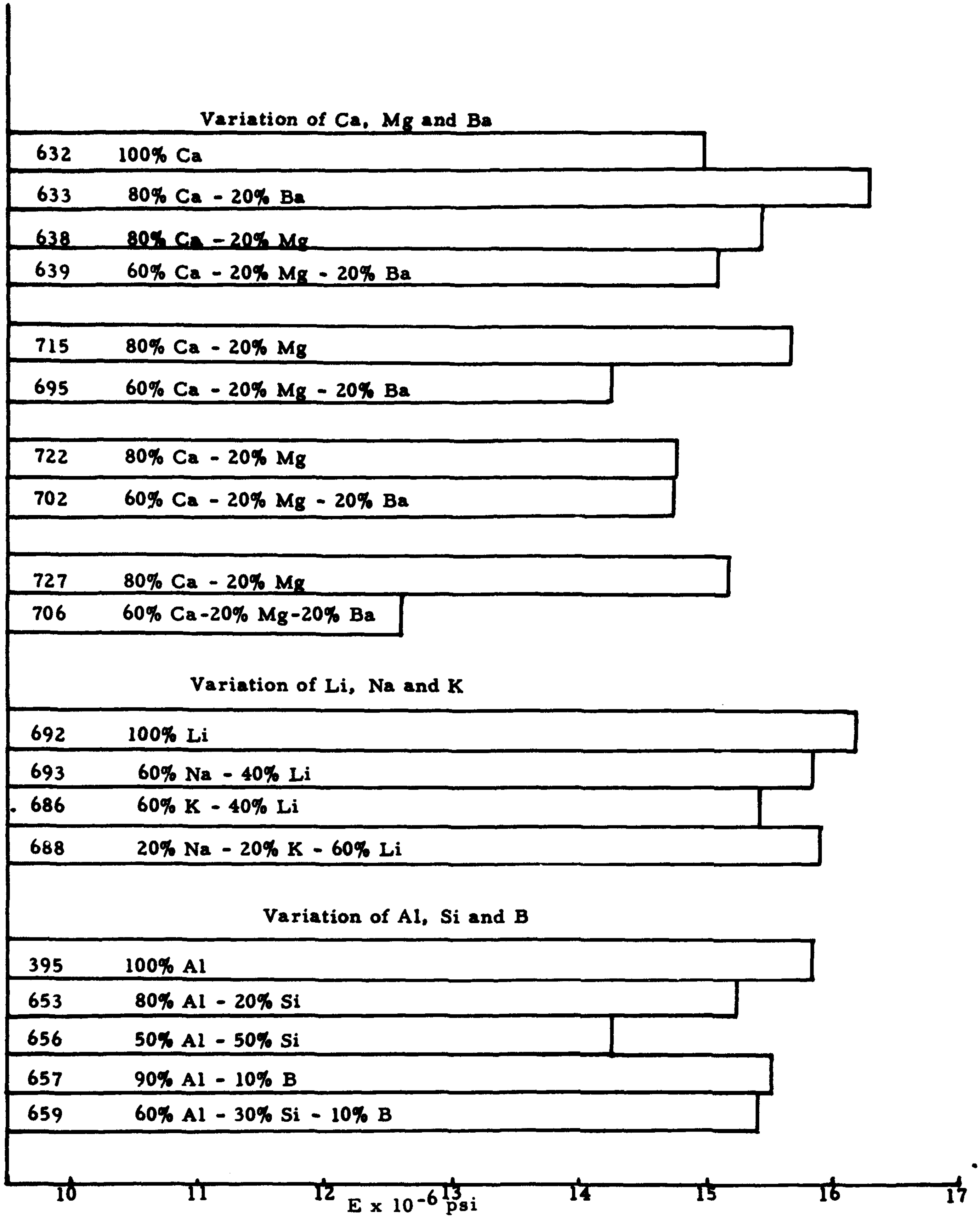

Fig. 2

Young's Moduli of Annealed Glasses

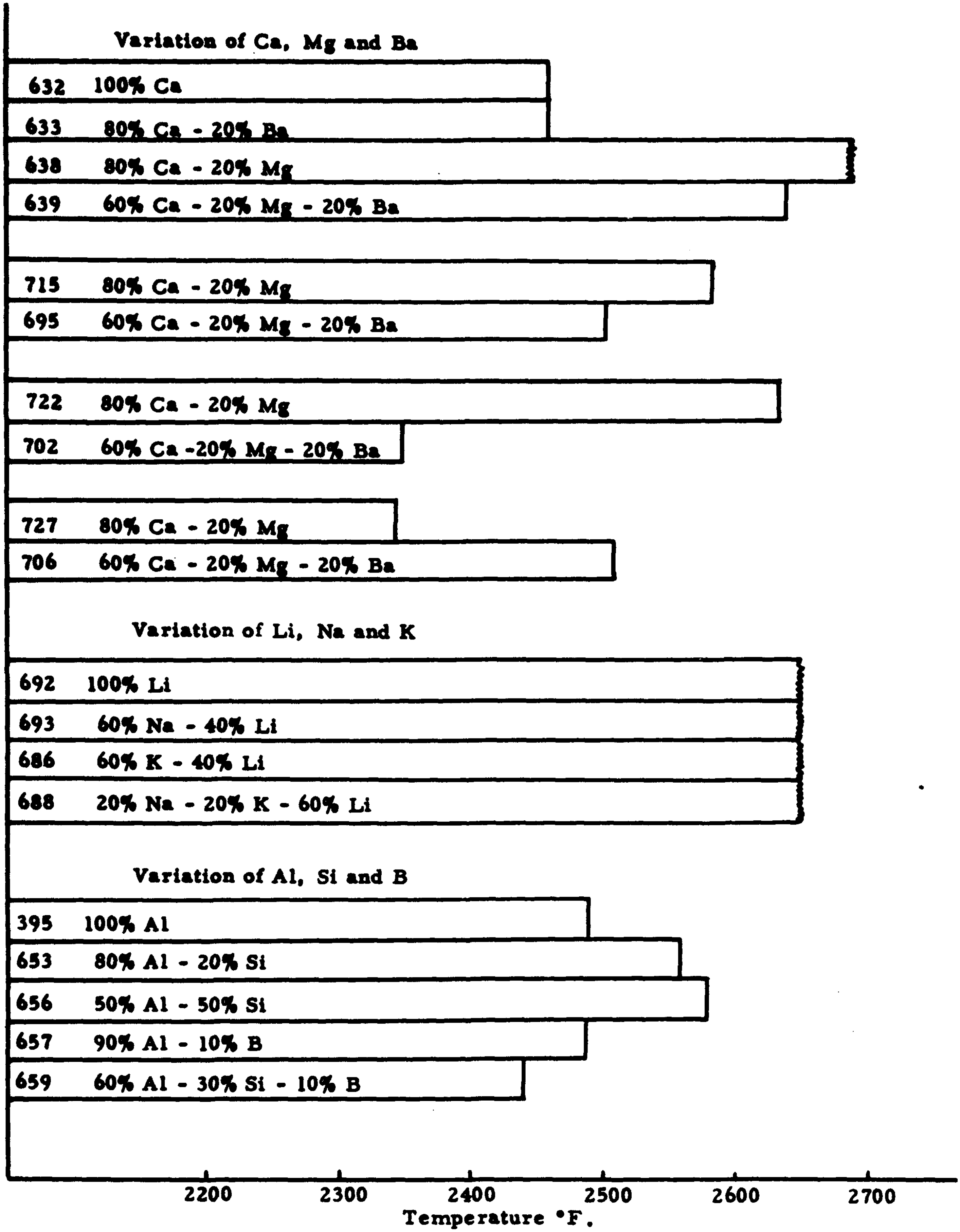

Fig. 3
Liquidus Temperatures

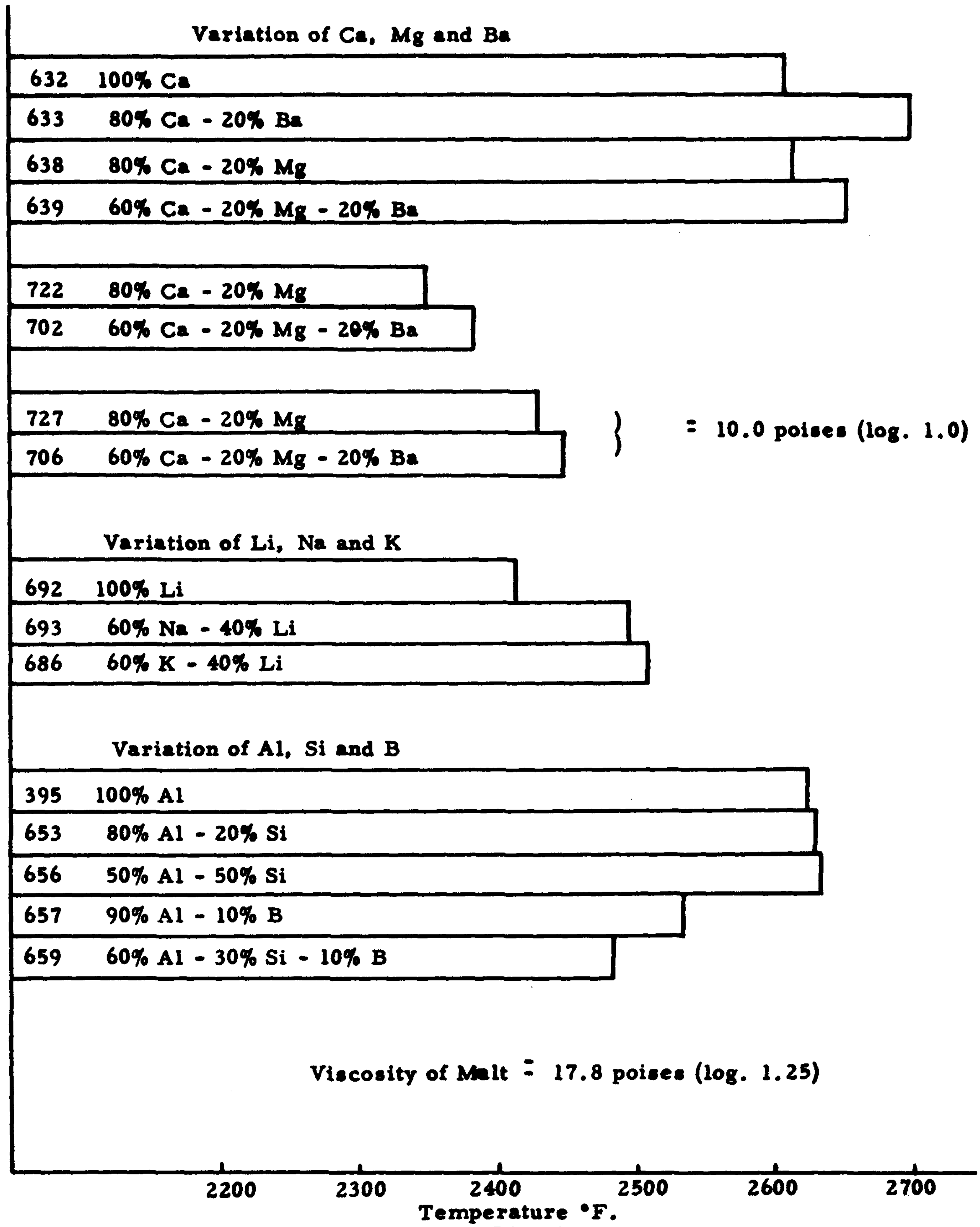

Fig. 4

Viscosity of Melt

IV. FIBER FORMATION STUDIES

The basic tool used in this investigation for the study of formation of continuous type fiber was the one hole bushing described in Appendix VI.

Nearly all the glasses in this study were found to be impossible to form into continuous type fibers in the one hole bushing for one of two reasons:

1. The melting temperature was too high to be practical to use in platinum, or

2. The viscosity of the glass was too low above the liquidus temperature and the glass would not form fibers continuously without devitrification of the glass in the bushing.

   The glasses studied in a one hole bushing are shown in Table II and Table IV. All glasses shown on Table II could be formed in clear patties relatively free of devitrification. However, when they were placed in a one hole bushing, nearly all would devitrify when the temperature was sufficiently lowered to produce fibers. Various techniques were tried to overcome this devitrification problem. The most satisfactory of these was an air jet directed at the base of the cone or the end of the tip. Using this technique, small quantities of fiber were produced of Compositions Nos. 492, 506, 508 and 511. Even this technique, however, failed to yield a continuous operation since devitrification of the glass in the forming cone occurred after a few minutes operation.

Of all the glasses tried in the one hole bushing, Glass No. 508 shown in Table II was the most easily formed and was the only glass which could be fiberized continuously with no trouble with devitrification. Composition No. 508 was, therefore, used for all subsequent fiber formation studies. Fibers were always prepared to have a diameter of approximately 0.00040 inch.

Composition No. 508 shown in Table II had a bulk annealed modulus of 15.42×10^6 psi. The same glass when formed into fibers had a modulus of 13.25×10^6 psi.

Webster Capps of the National Bureau of Standards measured the elastic properties of No. 508 in bulk form by their methods. He reported elastic moduli of 15.8×10^6 psi, 15.5×10^6 psi and 15.5×10^6 psi as the result of three measurements. The shear modulus of this glass was also determined and found to be 6.25×10^6 psi. Density of this glass is 2.91 grams per milliliter. The density of the fiber after formation could not be determined by our present method, because of the poor water durability of the glass. The density of the fiber, however, can be assumed to be somewhat less than 2.91 grams per milliliter of the annealed glass. These fibers could be heat-treated at 1100°F. to a modulus of approximately 15×10^6 psi. Tensile strength

values for these fibers corresponded very well with the tensile strength of standard textile fiber. Virgin fiber has a strength of approximately 400,000 lbs./sq.in. Chemical durability of these fibers, as mentioned previously, is extremely poor compared to our standard textile glass. However, since the primary use of this glass is to be imbedded in a plastic, it is impossible at this time to determine how much chemical resistance the glass must have. This can be decided only after the glass-plastic laminates have been made and a reasonable life has been determined for them. These glasses, in both bulk and fiber form, are completely soluble in hydrochloric and insoluble in hydrofluoric acid.

The next step in the study of the fiber formation of these glasses was a trial in a multiple tip unit. This unit contained eight tips having various bore sizes and tip lengths. Several modifications of this unit resulted in a unit which could be operated continuously with Composition No. 508. This unit was operated for several weeks continuously and was finally shut down due to contamination of the tips. Contamination of the tips was not due to the glass itself, but rather to the stainless steel probe used in starting the fibers.

Using the information gathered from the study of the one hole bushing and the six and eight tip units, a seventy-eight tip unit was constructed for the production of the strand. Difficulties were immediately encountered with this unit because of temperature distribution across the tip area and difficulties of trying to start fiber formation. The best temperature distribution that could be obtained on this bushing never allowed fiber formation from all the tips simultaneously. This unit was eventually shut down because of freezing of all of the tips due to devitrification. A second unit was constructed which had a better heat distribution than the first and operated at a higher temperature than the first. A maximum of approximately twenty tips could be operated simultaneously on this bushing. Temperature control of this bushing was the major difficulty. If the bushing was operating at too high a temperature, devitrification stopped the tips. This bushing was finally closed down after all the tips were closed by devitrification to the point where they could no longer be cleared. No samples of strand were ever produced on this type of bushing. Further developments of tips for this large size bushing will be required before strand will be produced.

V. GLASS-PLASTIC COMBINATION STUDIES

Glass fibers produced on the six tip unit were used to construct glass-plastic combinations in the form of fishing rod tips. (Appendix VIII). Glass fibers are in these test samples as individual filaments because the small unit on which they were produced did not permit the formation of strand. Glass samples were collected by cutting off the pulling collet below the bushing a hank of fiber containing approximately 40,000 individual filaments. If a coupling agent was applied, it was applied during the forming operation. The hank, after being cut from the winding collet, was saturated with resin, hung vertically under tension, and wrapped with cellophane tape to form the rod. The formed rod was then heat-treated to set the resin.

Table V shows the results of the measurements of flexural strength, Young's modulus and ignition loss of these rods. Standard textile glass rods were produced for comparative purposes, since no comparison could be made between these rods and similar rods produced from a strand produced on a standard commercial textile unit. Flexural strengths and Young's modulus for standard textile glass rods reported in Table V are lower than those normally found for this type rod sample produced from strand. This is probably due to the method of production of the samples. The highest strength and the highest modulus rods produced in this investigation were prepared from No. 508 with Volan A coupling agent.

Heat treatment of fibers of No. 508 with Volan A coupling agent applied destroyed the fibers. Heat treatment could be given to fibers with vinyltrichlorosilane coupling agent, but no improvement in the strength or the modulus was observed in the glass-plastic rod, as compared to fibers not heat-treated. An attempt was made to use silicic acid as a lubricant during the forming operation, heat treating the resulting fiber and applying Volan A coupling agent. These fibers resulted in the lowest strength glass-plastic rods produced.

Because of the failure of the larger type forming unit containing 78 holes, no glass-plastic rod samples were produced from strand. Better comparison between the calcium aluminate glasses and standard textile glass will be possible whenever rods of this type can be produced from strand instead of individual filaments. Individual filaments are difficult to fabricate into test rods because of unequal loading of all filaments during the formation of the glass-plastic rod.

TABLE V

PHYSICAL PROPERTIES OF GLASS-PLASTIC COMBINATIONS

Glass	Coupling Agent	Resin	No. of Samples	Average Flexural Strength, psi	Average No. psi x 10^{-6}	Ignition Loss in % loss
Std. Textile	Volan A	Plaskon 911-11	9	111.9	5.21	29.05
Std. Textile	None	Plaskon 911-11	22	113.0	5.10	34.0
Ca 508	None	Plaskon 911-11	12	103.2	6.85	26.98
CA 508	XF444	Plaskon 911-11	12	130.0	6.39	29.76
CA 508	XF444	Plaskon 911-11	18	150.3	6.90	25.43
CA 508	Volan A	Plaskon 911-11	18	178.5	7.23	38.25
CA 508	Vinyltrichloro-silane	Plaskon 911-11	18	154.1	6.67	28.09
CA 508	Vinyltrichloro-silane	Plaskon 911-11	6 (heat treated)	135.4	5.45	39.39
CA 508	Silicic Acid & Volan A	Plaskon 911-11	10 (heat treated)	68.4	6.34	16.61
CA 508	Silicic Acid	Plaskon 911-11	9	104.7	3.72	50.55

VI. GENERAL CONCLUSIONS AND SUMMARY

The accomplishments and conclusions that can be drawn from this investigation are as follows:

1. Glasses in the calcium aluminate series can be produced which have bulk elastic moduli between 14×10^6 and 17×10^6 psi.

2. Fibrous glass has been produced from a glass having a bulk annealed modulus of 15.42×10^6 psi, resulting in a fiber having a modulus of 13.25×10^6 psi.

3. Heat treatment of resulting fiber will restore the modulus to nearly 15×10^6 psi.

4. Fibers have been produced from a one hole bushing and from small multiple hole bushings, but no fibers were successfully produced from large production-sized units. Further development work in bushings will be required before commercial production of these glasses will be feasible.

5. Glass-plastic combinations have been produced which had properties equivalent to or greater than glass-plastic combinations produced from our standard textile glass in a similar manner.

VII. RECOMMENDATIONS

A further worthwhile compositional investigation could be the addition of beryllium oxide in larger quantities than was practical in our laboratories. The few glasses produced in our laboratory containing beryllium oxide were produced from beryl, beryllium aluminate silicate. Beryllium oxide itself was not used as a raw material because of its toxicity. It is believed that additions of beryllium oxide in substitution for calcium oxide would lead to large increases in Young's modulus of the glasses. This is in agreement with the trend observed in the increases in modulus as we go from barium oxide to calcium oxide to magnesium oxide in the alkaline earth series.

Search for high modulus glass in tin oxide, zirconium oxide, and titanium dioxide fields were unsuccessful, but if higher meltine temperatures could be used, this possibility of high modulus glasses could again be explored.

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APPENDIX I.

Hot Stage Microscope

A method for investigating a large number of compositions as rapidly as possible was found in the use of the hot stage microscope.

The hot stage was made of a platinum strip, 1/2 inch wide, 2-1/2 inches long and 0.060 inch thick. A spherical depression 1/2 inch in diameter and 1/8 inch deep was made in the center of the stage to hold the sample. A platinum - 13% rhodium thermocouple was attached to the bottom of the sample depression for the temperature measurement.

The electrical power was supplied from a 110 volt - 60 cycle source and two variable transformers were used for the control of the temperature.

Observation of melting and devitrification on the hot stage was made with a wide field stereomicroscope as shown in Fig. 2.

The hot stage was surrounded by refractory insulation when in operation to eliminate temperature variations of the hot stage by ambient conditions. A colored glass shield was used between the hot stage and the microscope objective to cut down the light intensity and to protect the microscope from excessive heat.

The observation of melting temperature on the hot stage was very successful. The melting rates and temperatures could be determined in a comparative manner very rapidly.

Measurement of the liquidus temperature of the compositions on the hot stage was only a crude estimation because the observed liquidus was dependent on the rate of crystallization of the melt and the rate at which the temperature of the stage was changed. The rate at which the temperature was changed was held as constant as possible with the method of control used.

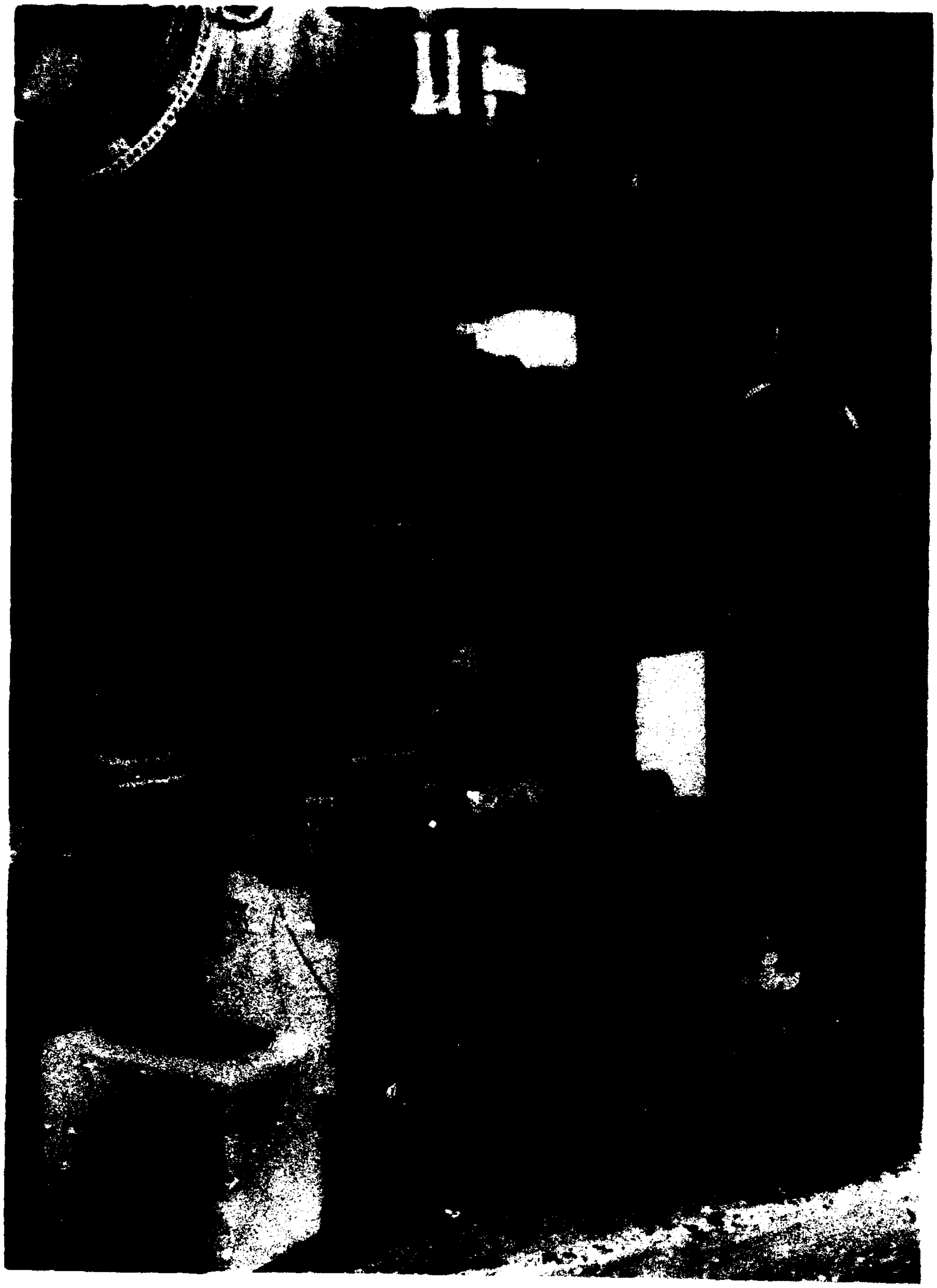


Fig. 5

Hot Stage Microscope

APPENDIX II

Determination of the Viscosity of Glass Melts with the Brookfield Viscometer

The Brookfield Synchroelectric Viscometer is a commercial instrument produced by the Brookfield Engineering Laboratories of Staughton, Mass. The principle of operation of these instruments is the accurate measurement of the torque on a spindle rotating at a constant speed in the viscous liquid.

This method of Margules has been widely used in the glass industry and its reliability well established. [7,8,9,10] Lillie eliminated the need for a calibration factor by determining the correction to be applied to the finite length of the rotating spindle.

The combination of the Brookfield Viscometer with the spindles developed by Lillie have resulted in a method of measurement which is simple, fast and reliable. The calculated calibration of the Brookfield Viscometer was checked by measuring the viscosity of several of our standard glasses of known viscosity-temperature relationships.

Fig. 6 shows the viscometer mounted above the crucible furnace, the furnace and the furnace controls.

Fig. 7 shows the Brookfield Viscometer, the platinum spindle, the platinum linkage and the sample crucible.

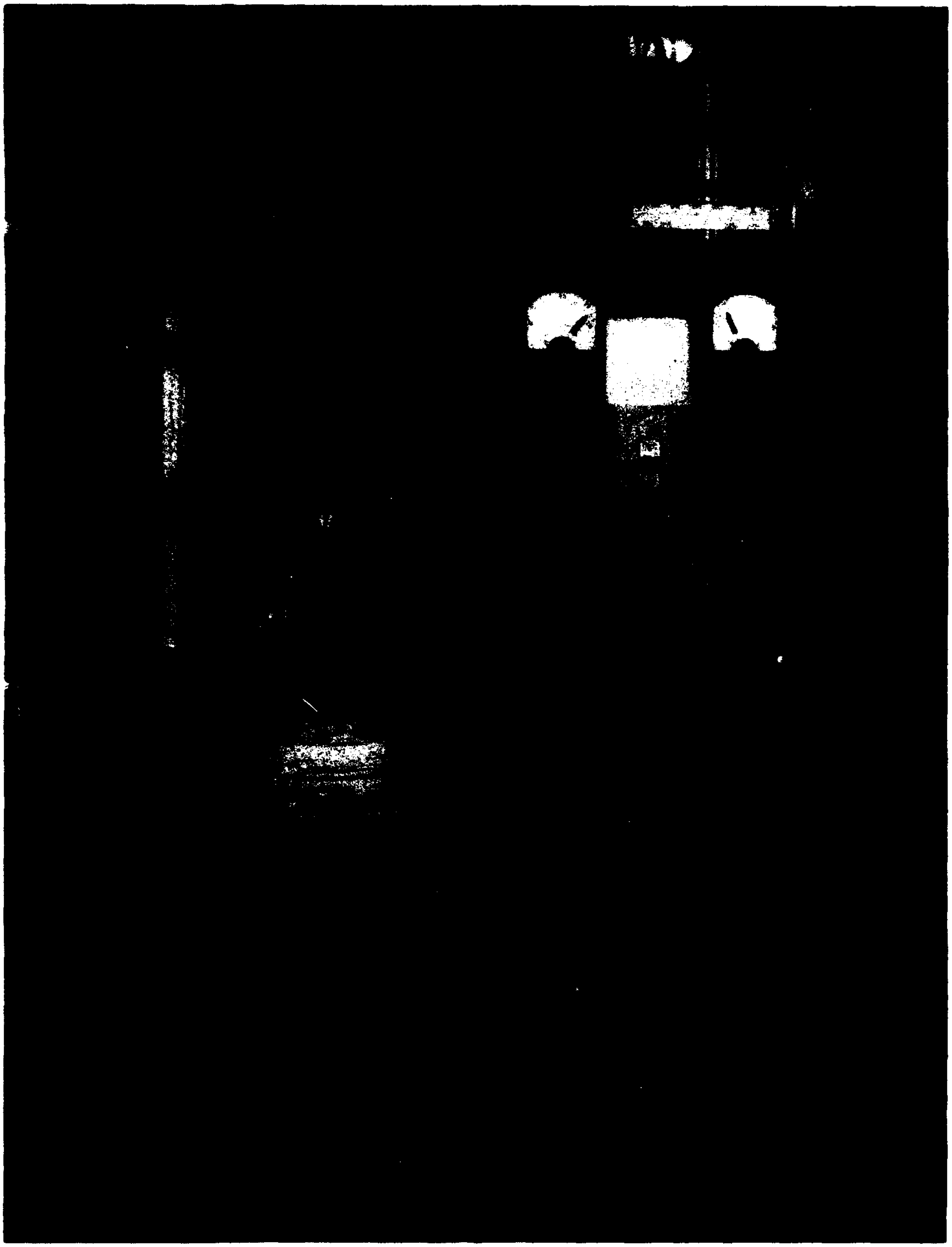


Fig. 6

Brookfield Viscometer Furnace and Control

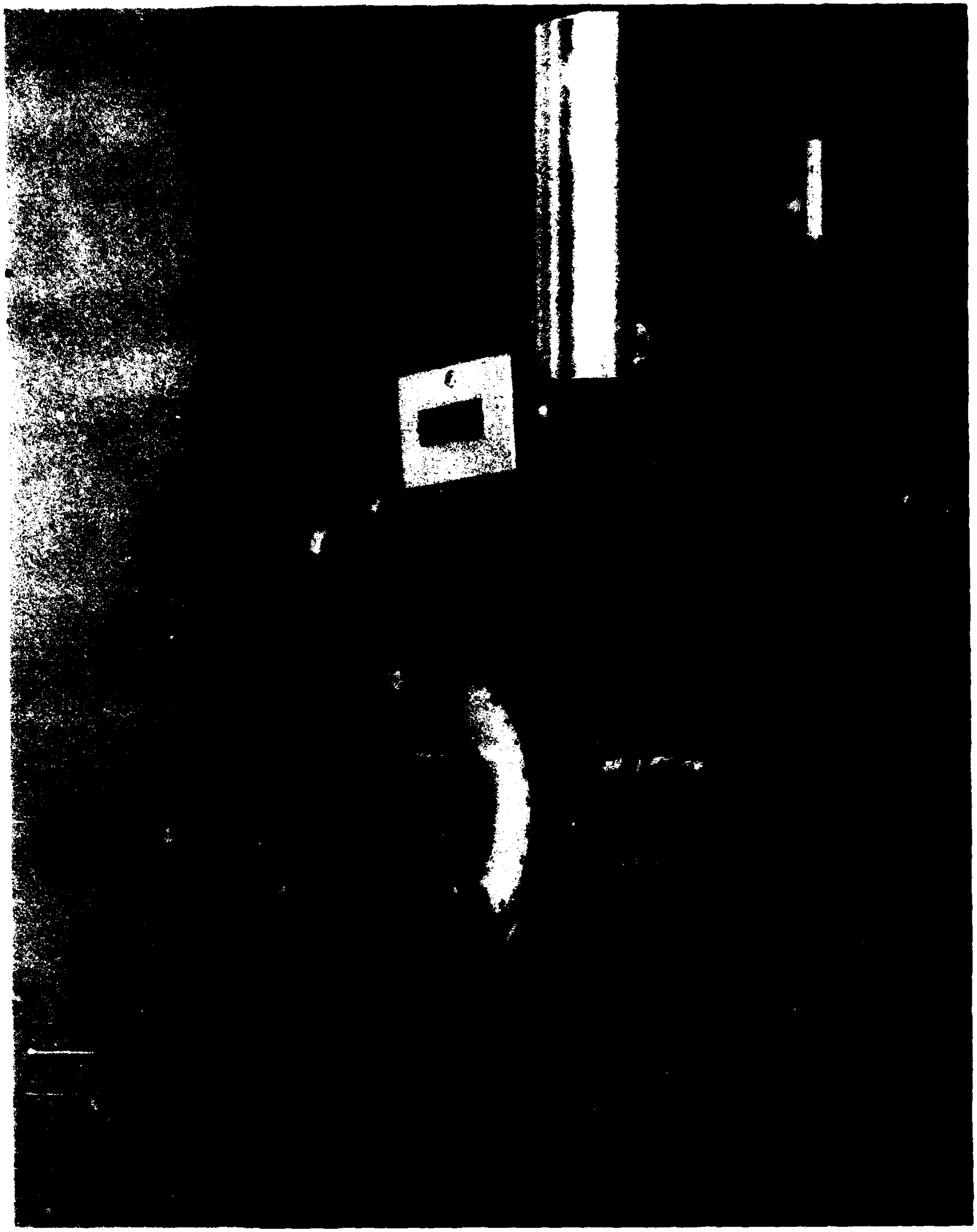


Fig. 7

Brookfield Viscometer

APPENDIX III

Determination of the Liquidus Temperature by the Gradient Method

This method of determining liquidus temperatures was first described by Tammann[2]. The method has been used by several other investigators.[12, 13, 14, 15]

The gradient furnace and furnace controls are shown in Fig. 8. The furnace is a platinum resistance tube furnace, constructed to produce a temperature gradient from the center toward each end. The temperature gradient in this furnace is approximately 40-50°F. per inch.

The sample boat is shown in Fig. 9. The glass was crushed and placed in the boat. The boat was six inches long and a temperature difference of 300°F. existed between the opposite ends of the boat when in the gradient furnace.

For many commercial glasses, several days are required to reach equilibrium between the crystalline and glassy phases. The glasses studied in the current investigation devitrified very rapidly and only one to two hours were required for each determination.

Fig. 9 also shows the effect of a very rapid devitrification rate on the determination. The crystals which formed while the boat was cooling in air have hidden the liquidus in one of these samples. Sudden chilling of the boat as it was removed from the liquidus furnace prevented crystal growth in the glass during this period.

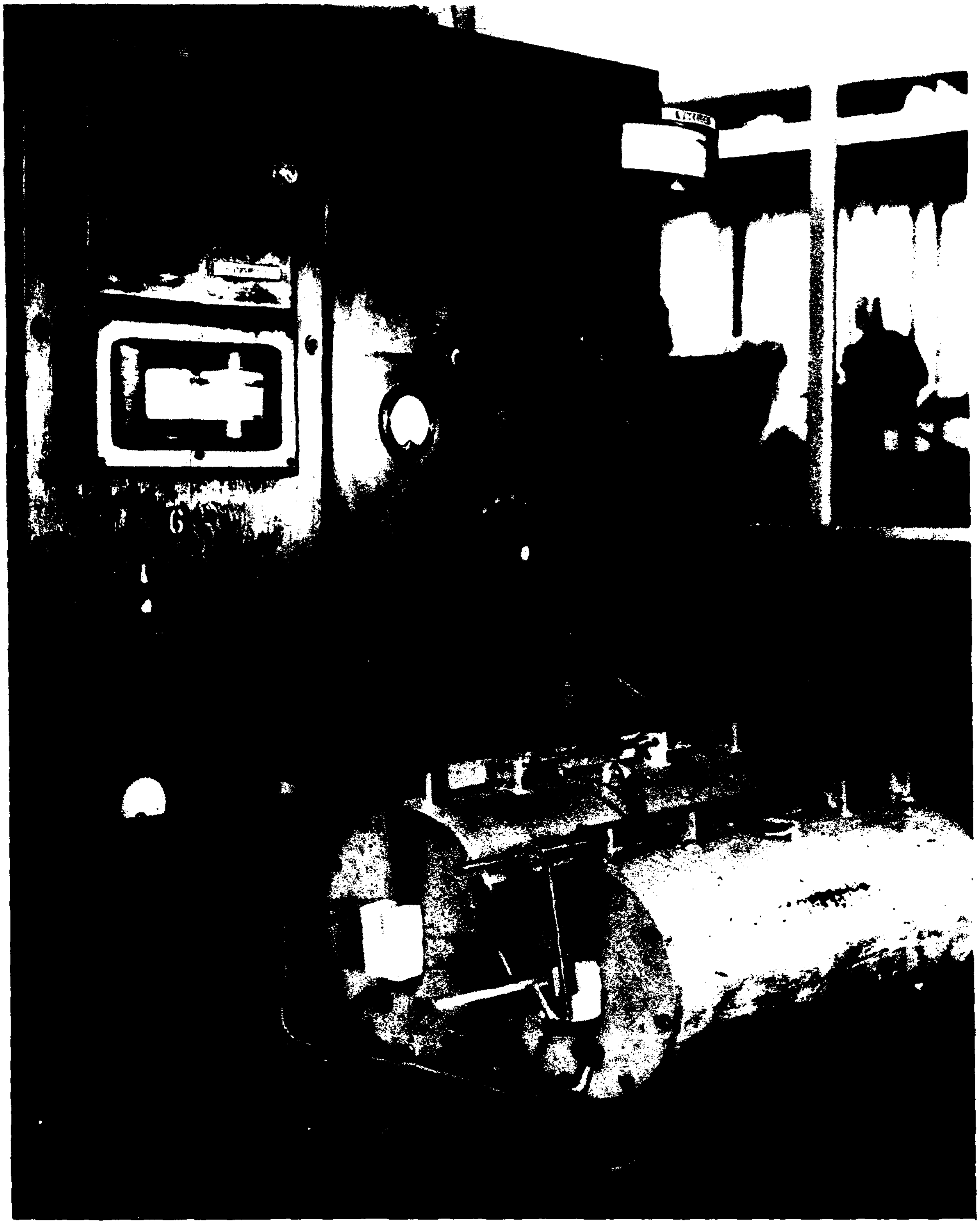


Fig. 8

Gradient Liquidus Furnaces

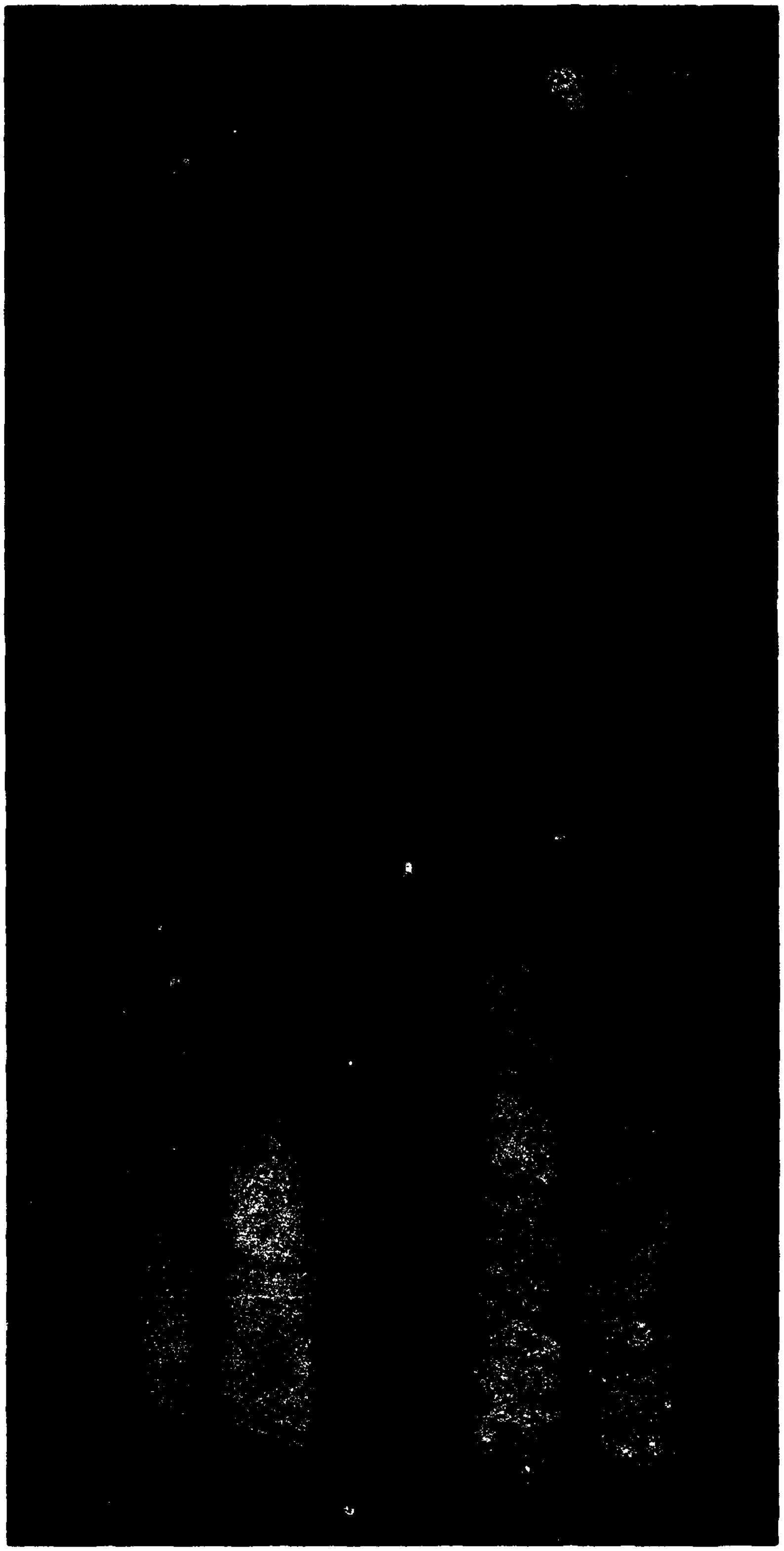


Fig. 9

Liquidus Boats

APPENDIX IV

The Surface Tension of Glasses
Determined by the Maximum Bubble Pressure Method

The maximum bubble pressure method was developed by Jaeger.[16] The method used in our laboratory is the modification developed by Parmalee and Lyon.

Fig. 10 shows the surface tension apparatus, furnace and furnace controls. Fig. 11 shows the platinum crucibles and the platinum capillary tips used in this apparatus. Air pressure was supplied from the laboratory compressed air supply and regulated to about 15 psi by a pressure regulator. The manometer reading was made with a measuring microscope used as a cathetometer. Measured surface tensions were reproducible to 1-2%, but the absolute error may be as great as ± 10%, particularly at low temperature and high viscosities.

The measurements required approximately one day for each glass. The capillary tip had to be kept clean and sharp, or serious error was introduced into the measurements. The individual bubbles had to be formed slowly to provide time for the glass to flow away from the bubble as it formed. High values were the result of too rapid formation of bubbles. Volatization from the surface was not observed as a serious problem.

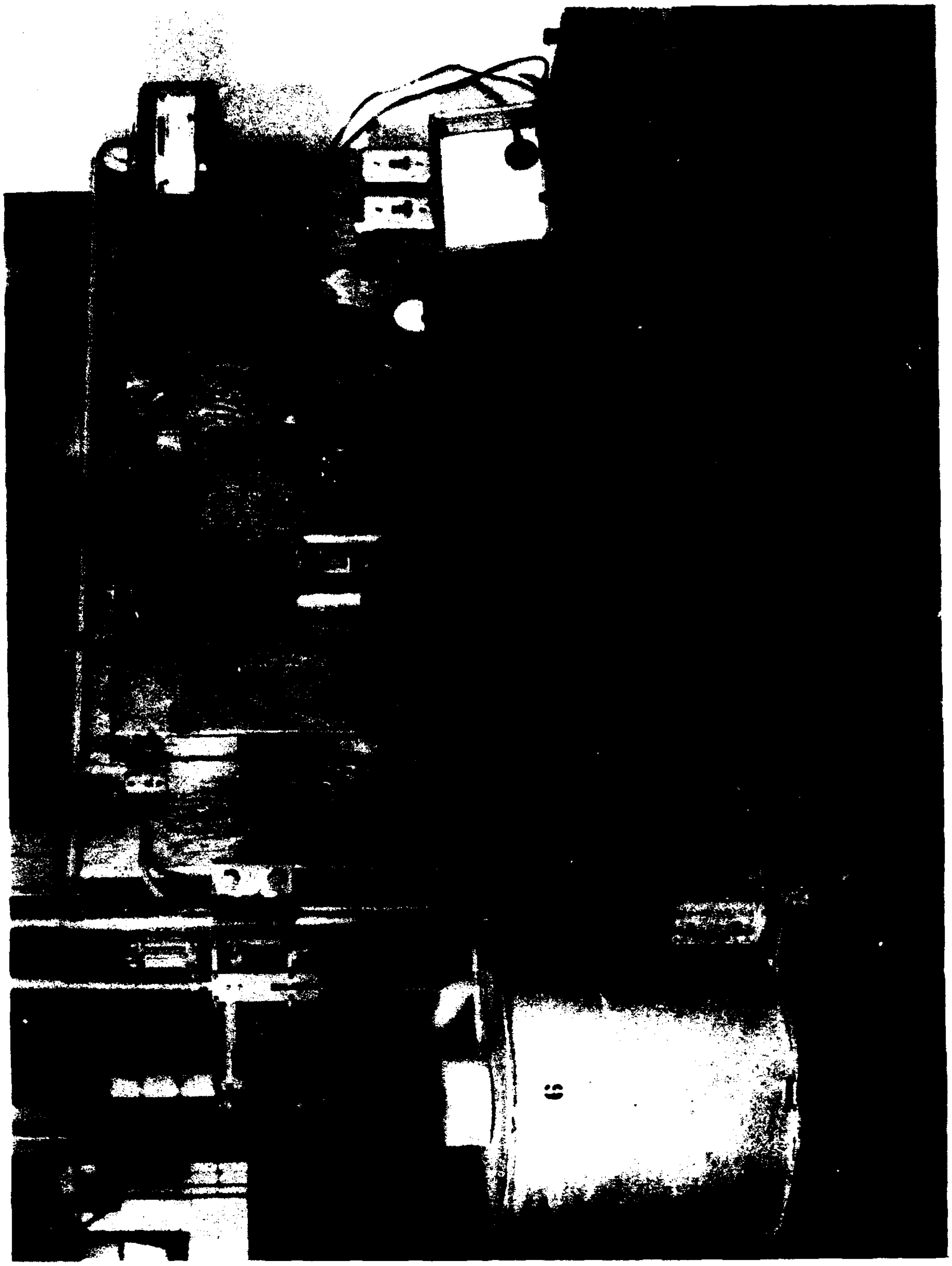


Fig. 10

Surface Tension Apparatus

Fig. 11

Crucible and Capillary Tube for Surface Tension Measurement

APPENDIX V

Measurements of Young's Modulus

Simple elasticity theory (that is, the theory by which we calculate the stresses and strains in structural members) assumes an elastic range of stresses in which the stresses and strains in a solid body are uniquely related and simply proportional to each other. The proportionality constants are called elastic constants, one of these being Young's modulus of elasticity.

$$E = \frac{\text{normal stress}}{\text{normal strain}}$$

The modulus is measured by applying a known stress and measuring the resulting strain. While the simple method is mechanical loading in a static system, a more convenient and more precise method in many cases is the dynamic or vibratory method. This latter method resolves itself into measuring the velocity of an elastic wave moving through the material since this is merely another method of elastically loading and unloading the material.

Measurement of Young's Modulus by Longitudinal Vibrations

For isotropic materials, the velocity of a longitudinal wave is determined solely by Young's modulus E and the density ρ.

$$E = \text{dynes/cm}^2$$

$$\rho = \text{grams/cc}$$

In practice, a bar of square cross-section was cemented on one end to a quartz crystal bar having the same resonant frequency. The crystal was then driven by a variable frequency oscillator and resonance of the composite was determined. The cemented joint had to be at a displacement antinode of the composite so that minimum stress was exerted on the joint.

The resonant frequency of the specimen was calculated from the following formula:

$$F_s = \frac{F_c(M_s+M_q) - F_qM_q}{M_s}$$

where F_q = resonant frequency of crystal (cycles/sec.)

F_s = resonant frequency of specimen (cycles/sec.)

F_c = resonant frequency of composite (cycles/sec.)

M_s = mass of specimen (grams)

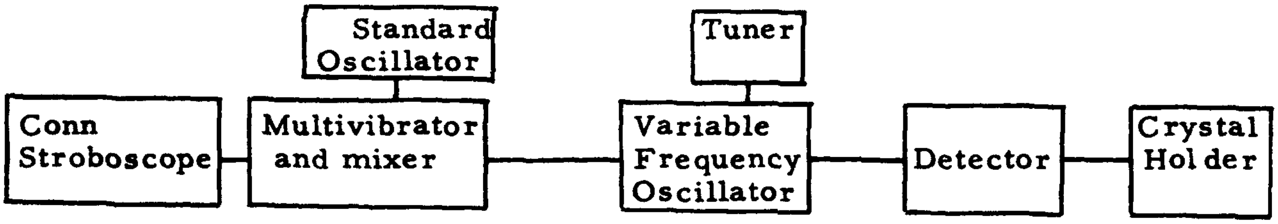
M_q = mass of crystal (grams)

then, knowing the length, l, of the specimen and the density, ρ , Young's modulus was calculated from the following relation

$$E = 4l^2 F_s^2 \rho$$

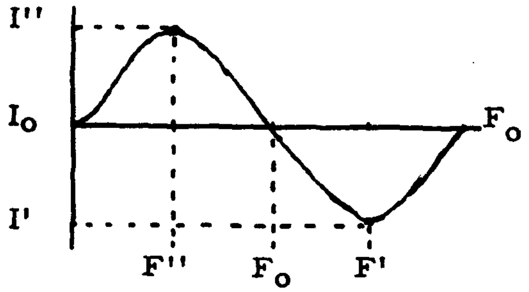
E = dynes/cm^2
L = cm $\quad \rho$ = grams/cc
F_s = cycles/sec.

A block diagram of the electrical circuit is shown below:



The standard oscillator was a controlled tuning fork, having a frequency of 1000 cycles per second with high harmonic content. This variable oscillator drove the crystal and was also mixed with the 1000 cycle signal and harmonics. This provided a beat signal which was fed to the Conn Stroboscope. For example, if the variable frequency oscillator was oscillating at 38,357.2 cycles per second, the beat notes produced with the 38th and 39th harmonics of the 1000 cycle oscillator were 357.2 cycles/sec. and 642.8 cycles/sec. This was fed into the Conn Stroboscope through a 0-500 cycle/sec. pass filter which attenuated the higher frequency. Then the lower frequency could be measured.

The detector was an electronic voltmeter which measured the voltage across a resistance in series with the crystal. This reading was then proportional to the current in the crystal. The current vs. frequency characteristic of a crystal is



$$F_o = F'' + \frac{I'(F' - F'')}{I'' + I'}$$

The crystal was of square cross-section, with two opposite faces silver plated. The electrical connections and supports were at displacement nodes.

Fig. 12 shows the complete apparatus for the determination of Young's modulus of bulk annealed glass rods. Fig. 13 shows in detail the sample and sample mounting.

Vibrating Reed Measurement of Young's Modulus

The velocity V of a flexural wave traveling in a rod of radius, is given by the relation

$$V = \frac{\pi r}{2\lambda}\sqrt{E/\rho} \qquad V = \text{cm/sec.}$$

where λ is the wave length in centimeters.

For the vibrating reed or fiber this relationship becomes

$$f_n = \frac{\pi K}{2\ell^2}\beta_n^2\sqrt{E/\rho}$$

where $K = r/2$ for circular cross-section of radius r (cm)

$f_n =$ resonant frequency at mode of oscillation (cycles/sec.)

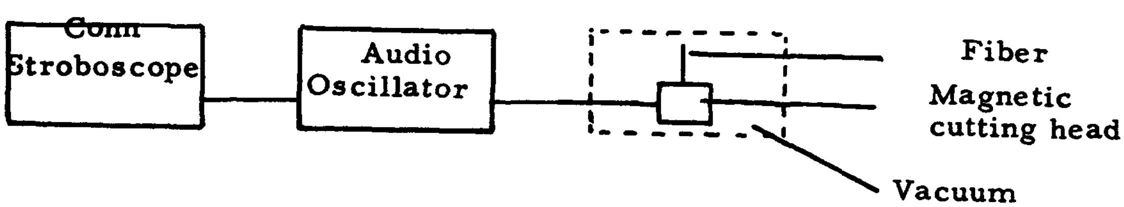
$\ell =$ length of fiber (cm)

β_n - is a factor depending upon mode of oscillation

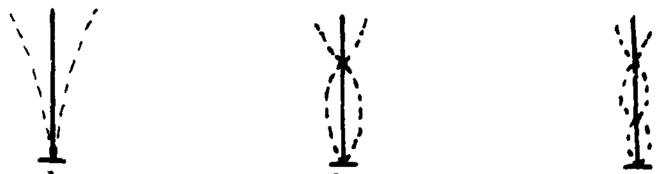
or $$E = \frac{16 f_n^2 \ell^4}{\beta_n^4 \pi^2 r^2}\rho$$ for each mode of oscillation. (dynes/cm^2)

Thus, Young's modulus can be calculated from measurements of resonant frequency for a particular mode of oscillation, fiber length, fiber diameter and density.

In practice, a magnetic phonograph cutting head was used to set the fiber to vibrating in one of its resonant modes of oscillation. This cutting head was driven by a variable frequency audio oscillator. As shown in the block diagram, the Conn Stroboscope was used to measure the resonant frequency.



The modes of oscillation and β_n values are shown below:



Mode	1	2	3
β_n	.597	1.494	$n - \frac{1}{2}$ $(n > 2)$

Fig. 14 shows the complete apparatus for the determination of Young's modulus on fiber samples. Fig. 15 shows the detailed mounting of the fiber sample.

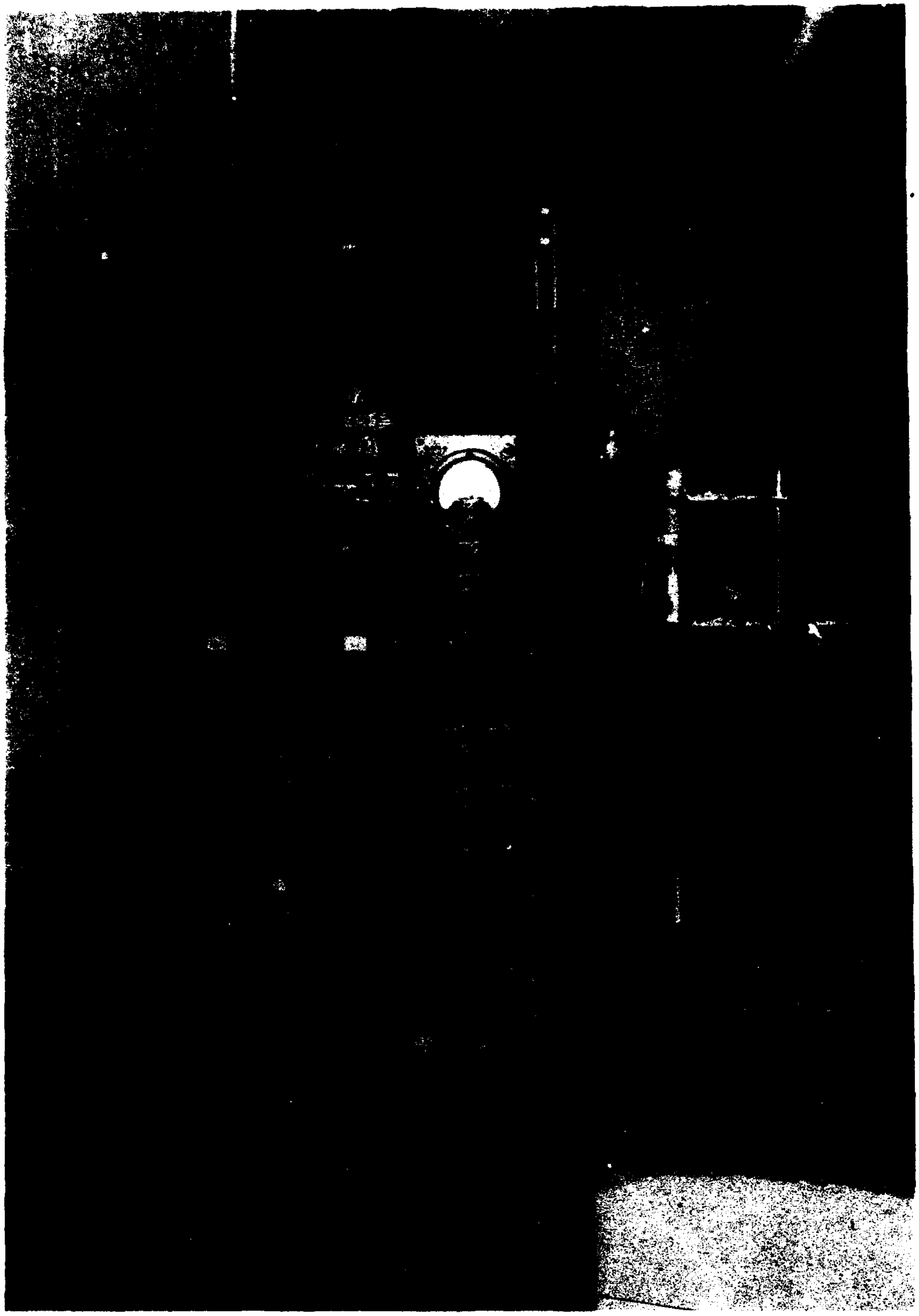


Fig. 12

Young's Modulus Apparatus for Bulk Samples

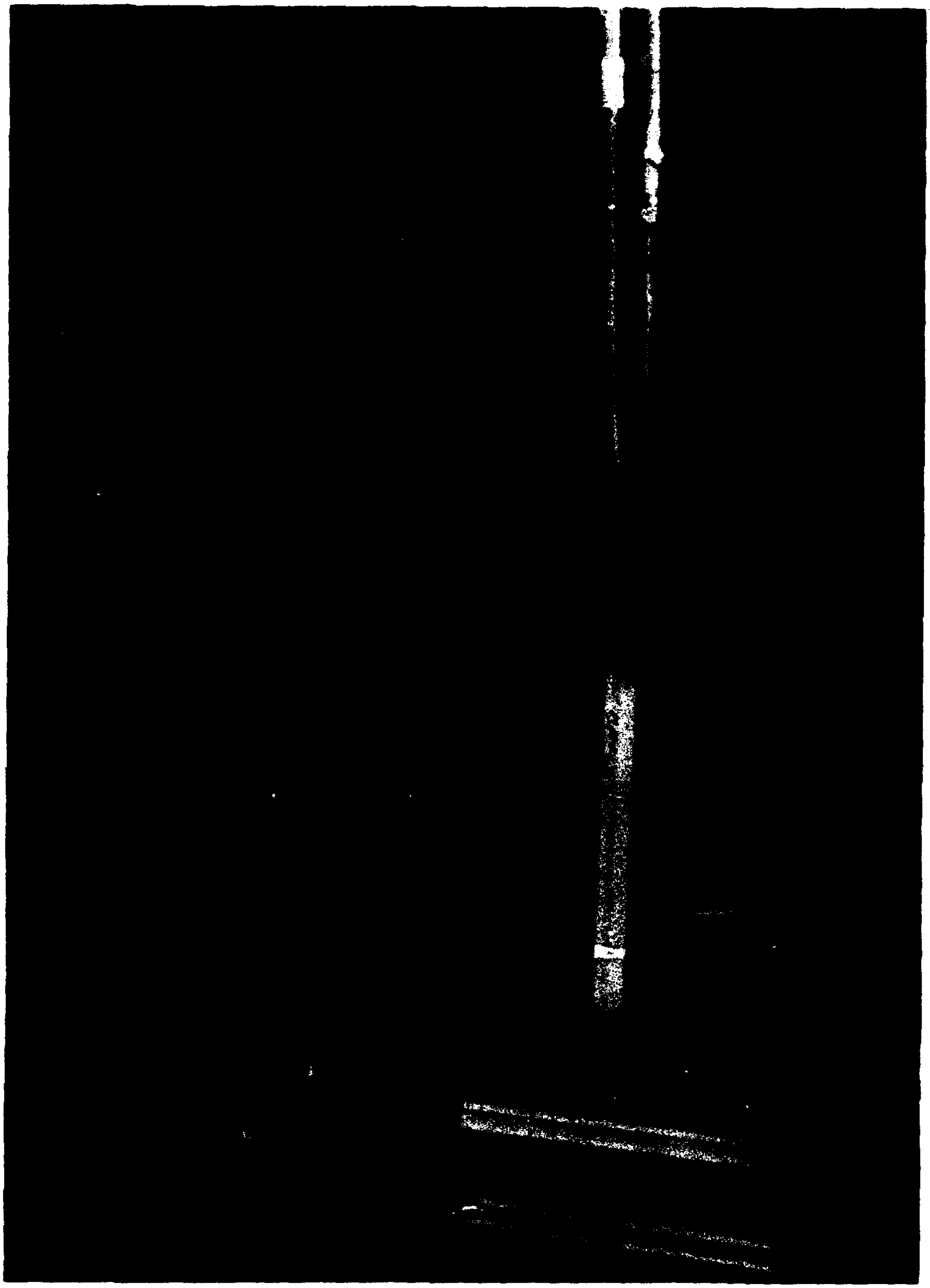


Fig. 13

Sample Mounting for Young's Modulus Measurement

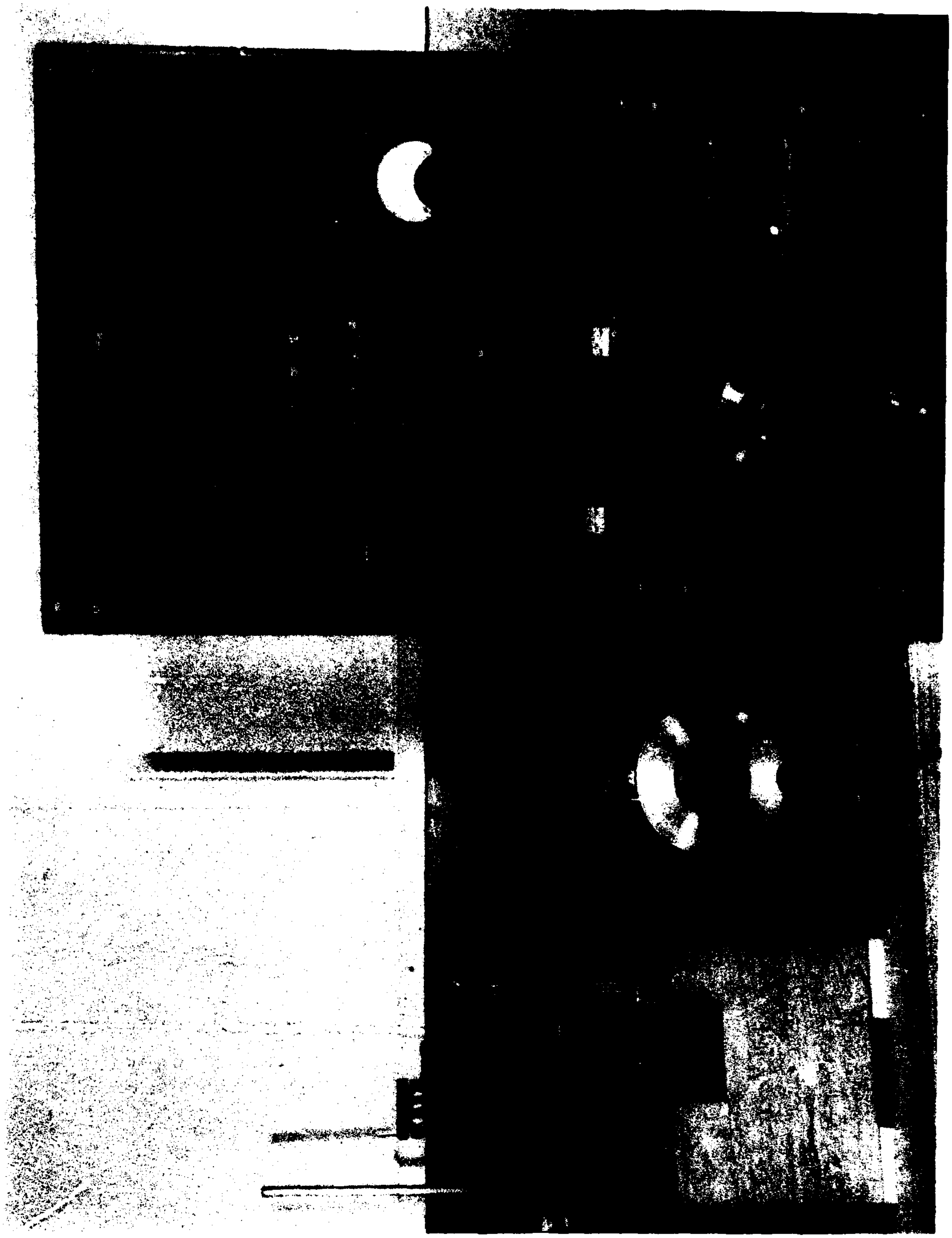


Fig. 14

Young's Modulus Apparatus for
Fiber Samples

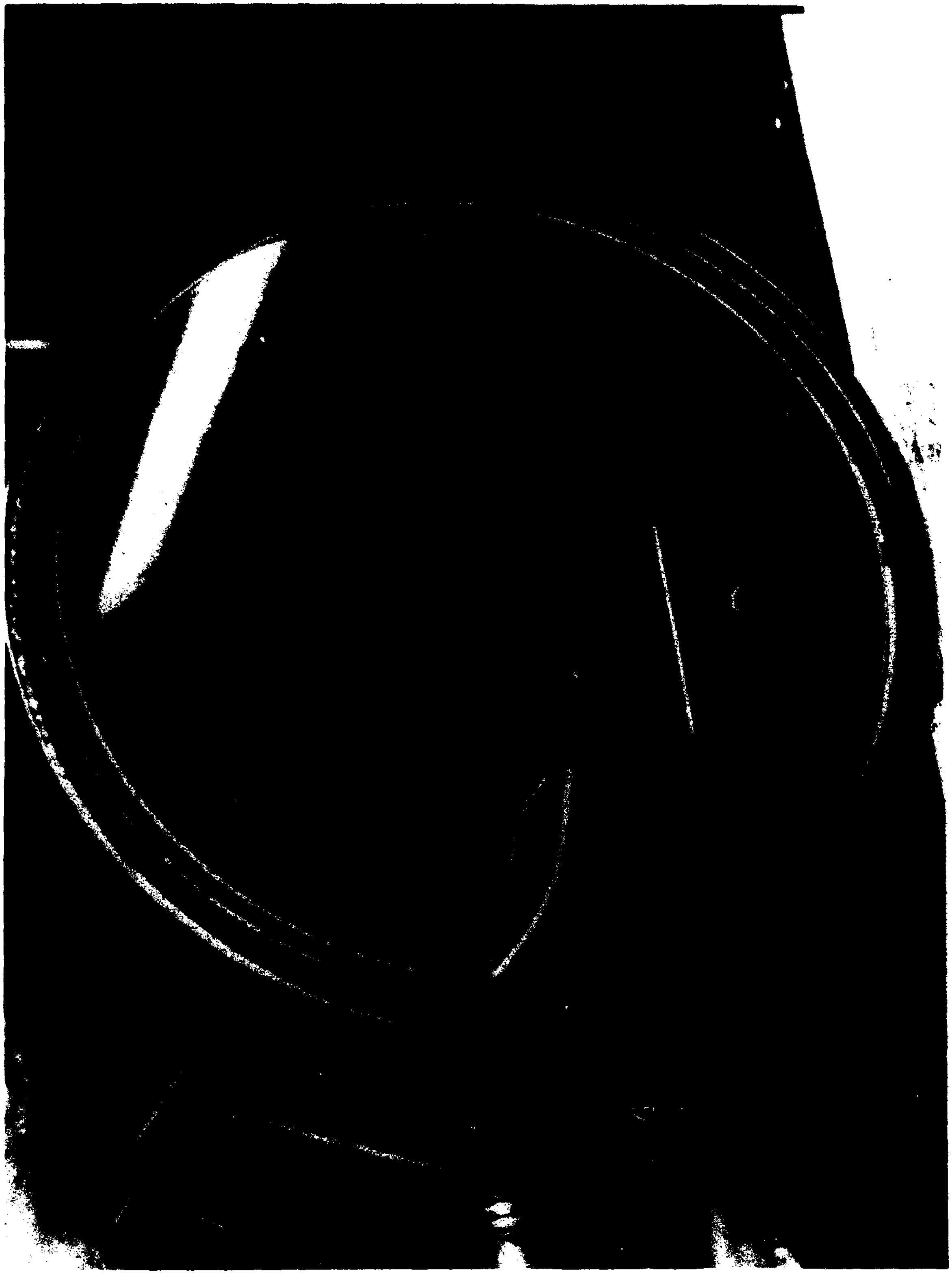


Fig. 15

Fiber Sample Mounting for Young's Modulus Measurement

APPENDIX VI

Fiber Forming Apparatus

The standard method of forming continuous glass filaments on a laboratory scale has been described by Tiede.[19] Many modifications of the simple one hole bushing can be used for investigating the feasibility of producing glass fibers.

Fig. 16 shows the complete assembly as it is used for a viscosity measurement as described by Tiede. Fig. 17 shows the platinum bushing without insulation.

The tip of the bushing can be varied in many ways. The metering hole which regulates the rate of flow of the glass into the tip can be varied to regulate the final fiber diameter. The tip can be counterbored or plain. Counterbored tips help prevent flooding of the bushing. The tip can be cooled by an air jet or water coolers to help stabilize the cone of glass from which the fiber is drawn.

The pulling speed or rate of fiber forming can be changed by using a variable speed motor on the pulling wheel. Rates of drawing from 1000 ft./min. to 9000 ft./min. can be obtained with our laboratory equipment.

Fiber diameter can be regulated by bushing temperature, metering orifice size or pulling speed. The most satisfactory combination of these variables must be found for each glass investigated.

Fig. 16

One hole Bushing Apparatus

Fig. 17

One hole Bushing

APPENDIX VII

Single Fiber Tensile Tests

Single fibers are tested in simple tension on the constant rate of strain apparatus shown in Fig. 18.

This apparatus employed a cantilever beam type weighing cell with coupled LVDT (linear variable differential transformer). The LVDT was powered at 8000 cycles/sec. and the output signal from the LVDT after passing through the bridge-amplifier and rectifier, was fed to the X-axis of a Leeds and Northrup X-Y recorder. A signal, from a potentiometer coupled to the loading jaw, was fed to the Y-axis of the recorder, thus providing a load-elongation diagram for each fiber tested.

Fibers were taken from the fiber forming apparatus and mounted on wire holders for transfer to the testing machine, care being taken to eliminate damage to the fiber by handling. The fibers were secured to the jaws of the tensile tester with red sealing wax as shown in Fig. 19.

After each fiber was tested, a portion of the fiber was mounted on a microscope slide for measurement of fiber diameter. This measurement was made by projection microscopy at a magnification of 1000X. The tensile strength of each fiber was then calculated from the breaking load and the diameter (cross-sectional area).

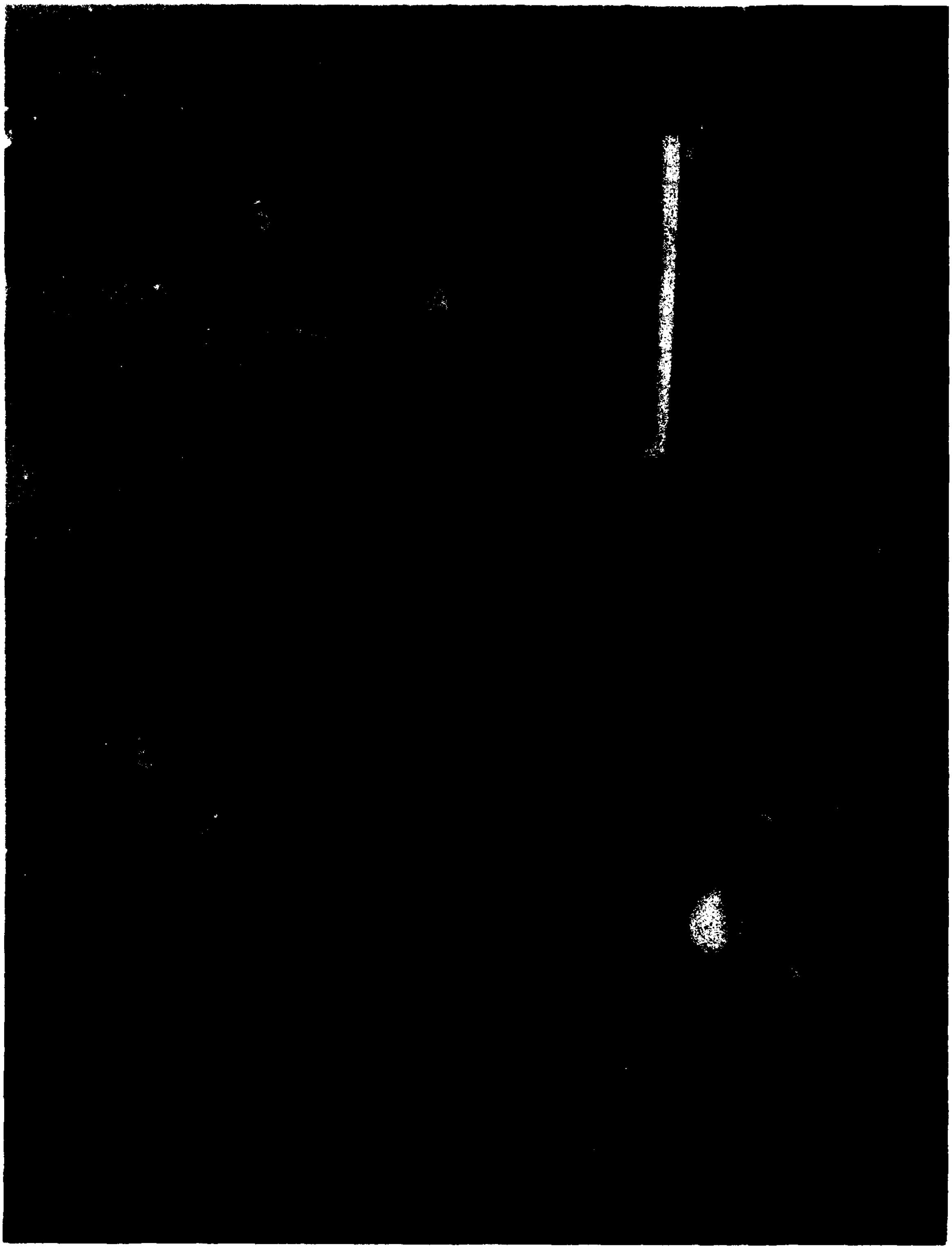


Fig. 18

Tensile Strength Measurement

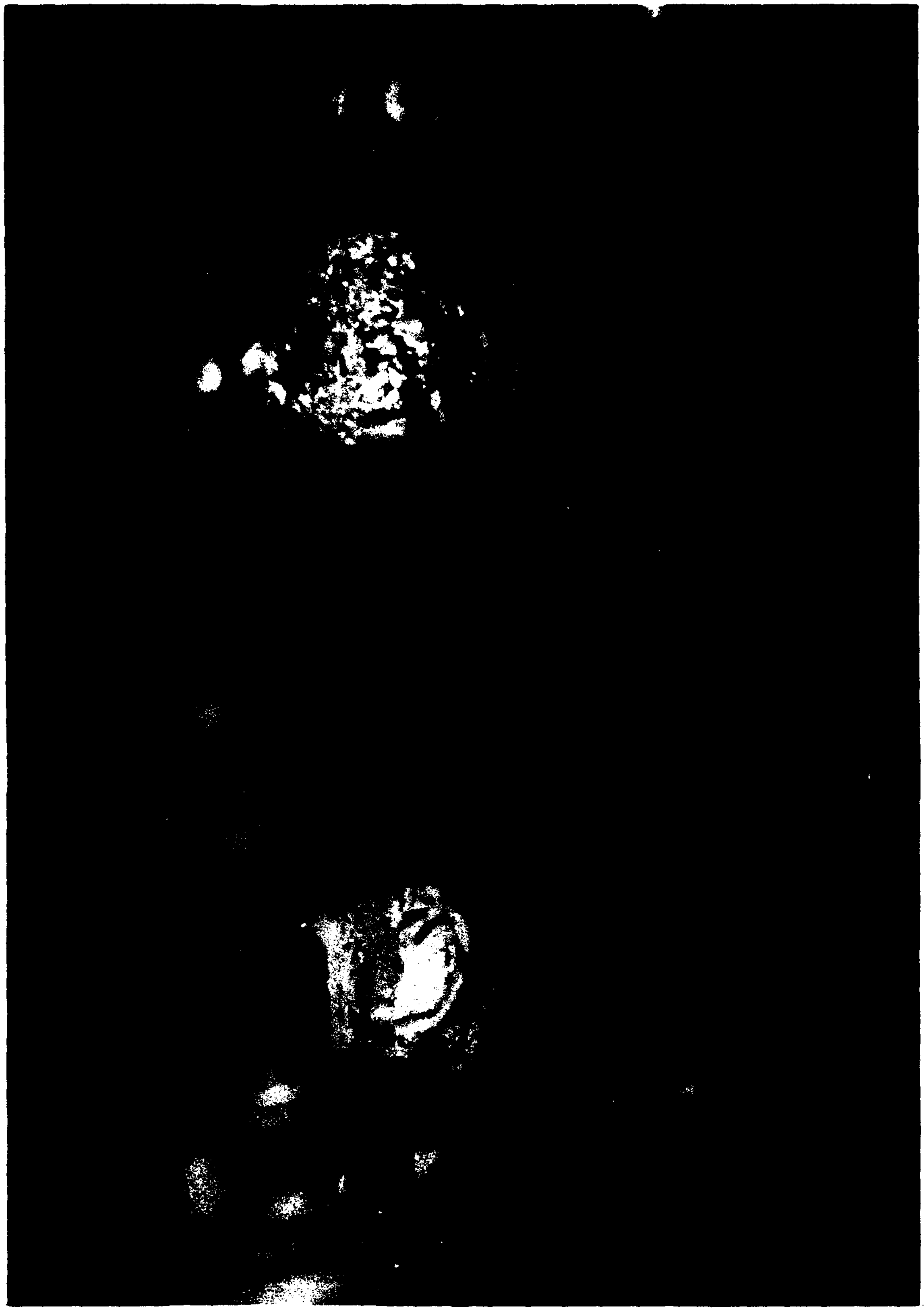


Fig. 19

Sample Mounting for Tensile Strength
Measurement

APPENDIX VIII

The Formation of Glass-Plastic Test Samples

The standard "fishing rod tip" test samples of fibrous glass-plastic materials are produced as follows:

1. A length of strand containing 204 filaments is impregnated with a thermosetting resin.

2. The impregnated strand is looped about two hooks approximately 20 inches apart until a strand of approximately 40,000 filaments is built.

3. The lower hook on the strand is stressed to hold the fibers straight and the entire rod of 40,000 filaments is wrapped, by machine, with cellophane tape.

4. The cellophane wrapped rod is heat treated to fix the resin and the rod is complete and ready for testing.

The equipment used in producing these samples is shown in Fig. 20.

The test rods produced in this investigation differed from the above procedure in that no strand of 204 filaments was available. The following procedure was therefore followed:

1. A hank containing approximately 40,000 filaments was cut from the winding collet of the one hole bushing.

2. The hank was impregnated with resin, suspended under tension and wrapped with cellophane tape in the same manner as the strand.

3. The wrapped rod was heat treated and tested.

This second procedure with hanks of fiber is not as satisfactory as with strand because it is extremely difficult to put equal tension on all the individual filaments while the rod is being formed. As a consequence, the strength and modulus values obtained for this second procedure are less than those found with strand.

These tests are indicative of the overall properties of the glass-plastic combination. Therefore, the glass properties and the coupling between the glass and plastic, both affect the test results.

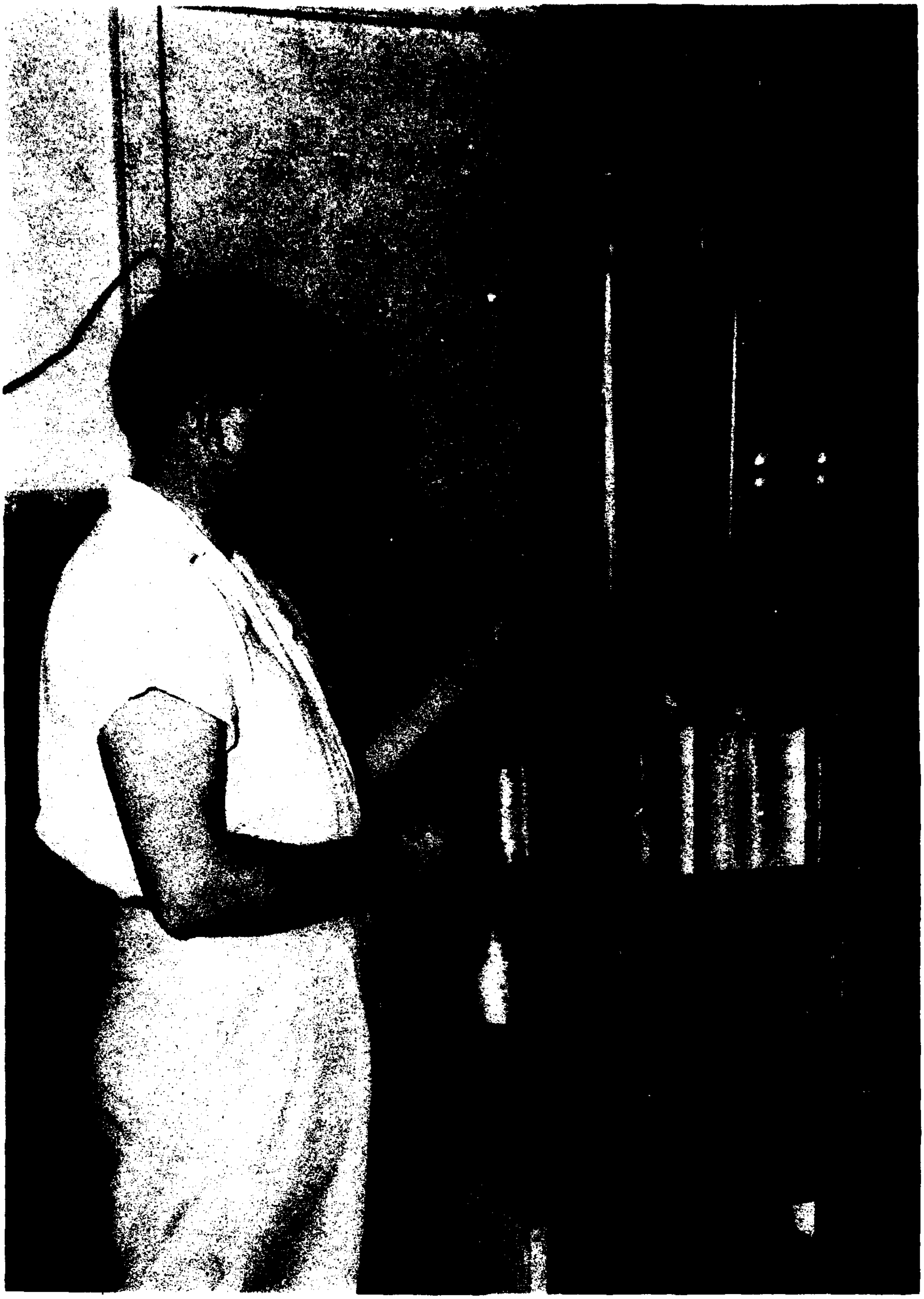


Fig. 20

Preparation of Glass-Plastic Rod Samples